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Contents for August, 1921

EFFECTS UPON THE GROWTH OF POTATOES, CORN AND BEANS RESULTING FROM THE ADDITION OF BORAX TO THE FERTILIZER USED

J. R. NELLER

Formerly of the New Jersey Agricultural Experiment Station

AND

W. J. MORSE[1]

Maine Agricultural Experiment Station

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In 1876 Peligot (14) grew beans in porous pots, the soil of which was moistened with a 0.2 per cent solution of either boric acid, potassium borate or sodium borate. He reported that the plants were killed in all cases. Nakamaura (13) states that borax at the rate of 50 mgm., and in some cases 10 mgm. per kilogram of soil, was harmful to plants in pot cultures. Within stated limits Agulhon (1) found that boric acid caused a stimulation of the growth of wheat in water cultures. He also maintains (2) that the seeds of corn grown and matured in soil containing boric acid, when planted again in such soil, produced plants which were more resistant to boric acid and gave larger yields than plants from seeds grown under normal conditions. Working with water cultures, Brenchly (3) found that boron was one of the inorganic substances which may both poison plants and cause a stimulation within certain limits—the stimulation differing for different plants. Lipman (9) found that a commercial limestone containing boron, besides depressing plant growth also depressed the ammonifying power of the micro-flora of the soil. Cook (5) studied the absorption and distribution of boron in certain cereals, legumes and garden vegetables when borax and calcined colmanite had been added, as larvicides, to the manure used as fertilizer for these plants. This work was continued by Cook and Wilson (7), who paid particular attention to the effects of the presence of boron upon the plants themselves. The same writers (6) also have reported upon the effect of three annual applications of boron on wheat. At the rates applied, the addition of borax and colmanite to manure used to fertilize peach trees seemed to have a stimulating effect.

[1] Dr. Neller introduced the system of soil moisture control and had sole charge of the experimental work recorded herein. The last named author is responsible only for the original, detailed plans and for assistance in the final revision of the manuscript.—W. J. M.

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No injury was observed with some of the other varieties of plants tested, while with others visible injury or reduction of yields or both occurred, and this amount of injury increased as the amount of boron added was increased. From the results of these experiments it is evident that a considerable variety of agricultural crops can be grown in comparative safety on soils to which relatively large amounts of borax have been applied, provided this borax is first thoroughly mixed with a considerable quantity of stable manure. A number of different factors are involved, however, for the authors state (7, p. 470) that:

> The absorption of boron by plants varies with the variety of plant, the solubility of the boron compound, the quantity of the boron compound added to the soil, the time elapsing after the compound is mixed with the soil before planting, the amount of rainfall, etc., and finally with the character of the soil to which the boron compound is added.

Recent field observations in different parts of the United States, which have been reported by Proulx and his associates (15), Conner (4), Morse (12), and Schreiner, Brown, Skinner and Shapovalov (16), have shown that definite and often severe types of crop injury are frequently associated with previous applications of fertilizers containing boron in water-soluble form. This led one of the writers (12) to conduct a series of greenhouse experiments in the fall and winter of 1919–20, mostly with potatoes, in which the effects of commercial fertilizers containing borax in various amounts were compared with those obtained from a similar, but not otherwise identical, fertilizer which was borax-free.

In these experiments definite and in some instances severe injury was obtained where fertilizers containing borax were used for potatoes and beans grown in pots in the greenhouse. No injury to the same crops resulted from the use of a borax-free fertilizer otherwise of similar composition. It was recognized that these preliminary experiments were deficient in certain respects. Possibly the most fundamental objection that could be raised to them was that while they showed quite clearly that the injury occurred only where fertilizers containing borax were applied, they provided no conclusive data to prove that borax was the sole toxic agent involved. It was planned to repeat and amplify these experiments as far as the limitations of greenhouse space at the Maine Station would permit. While the work was in progress Director Woods of Maine, at a meeting of the directors of the Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York and New Jersey stations, made a report of the results already obtained. In the discussion which followed it developed that the executives of these various stations were all interested in making a study of the toxic effect of borax in commercial fertilizers. From the standpoint of both efficiency and economy it was evident that such a study could be carried out best as a single joint project, each station bearing its proportionate part of the expense involved. Fortunately, a greenhouse well adapted to the purpose was avail-

able in Vermont and Director Hills' offer to place this at the disposal of the cooperating stations was accepted. The director and pathologist of the Maine station were requested to assemble the necessary fertilizer materials and to prepare the detailed plans for the experimental work. Director Lipman of New Jersey was given authority to select a suitable person to carry on the greenhouse work in Vermont. These details are mentioned in order to make it clear that the work here reported was undertaken and carried out under the joint auspices of eight different institutions in as many different states. In this respect it is believed that it establishes a new record for cooperation among experiment stations.

GENERAL SCOPE OF THE EXPERIMENTS

The chief purpose of the experiments herein described was to determine whether the injuries previously observed both in the field and in the greenhouse were due alone to the borax present in the fertilizers applied and, if so, what is the maximum amount of borax that can be applied per acre to land on which important food crops are to be grown, without causing this injury. Potatoes, corn and beans were selected as representatives of three different types of such crops. The plan outlined provided that the soil in a pot containing borax, for example, should differ only in this one respect in its fertilizing treatment from a pot of the same soil containing none of this substance. Hence, as is pointed out below, all the fertilizer used consisted of a single basal mixture prepared from materials of known composition and borax-free. As will be seen on reference to the detailed account of the work, other important questions were considered also. Attempts were made to determine the effect of distributing the fertilizer above and below the seed or seed-piece, both in drills and mixed with the soil.

Recently several persons have reported a neutralizing effect of certain calcium salts toward inorganic plant poisons. McHargue (11) found that the addition of small amounts of calcium carbonate checked the poisonous effects of barium and strontium salts and caused them to be stimulating at certain concentrations. Truog and Sykora (17) tested the influence of calcium carbonate and kaolin on the inhibition of the toxic effects of copper sulfate, copper nitrate, vanillin, sodium arsenite and quinidine carbonate and obtained positive results. The effect of lime upon the sodium chloride tolerance of wheat seedlings was found by Le Clerc and Breazeale (10) to be quite marked.

The work of Cook and Wilson (7) indicates that stable manure might in some way neutralize or prevent the toxic action of boron upon plant growth. For this reason it seemed desirable to attempt to determine whether some substance could be added to fertilizers containing borax, which would neutralize its toxic properties either wholly or in part. Ground limestone, hydrated lime, gypsum and manure were the materials employed for this purpose in the experiments under consideration. The amounts and the methods of use are discussed in the sections devoted to the different crops tested.

EXPERIMENTAL PROCEDURE

The soil available during the winter of 1920 when this work was started, had been composted with lime and a medium amount of manure for over a year. It was allowed to become nearly air-dry and was then passed through a ¼-inch mesh sieve. This removed some of the organic matter, the content of which was further reduced by adding sand equal to about one-third of the volume of the soil. As used the soil resembled a sandy clay loam and had a maximum water capacity of 37.5 per cent by the Hilgard method (8). It contained 4.22 per cent of volatile matter and had a lime requirement, or absorption coefficient, of 320 pounds per acre (2,000,000 pounds of soil).[2] The pots employed consisted of solid glazed jars. Two sizes were used, of diameter 8¼ and 5½ inches and of depth 8½ and 7 inches, respectively. The use of solid glazed jars prevented any possible accumulation of borax or fertilizing constituents such as may occur in the walls of porous pots as a consequence of the constant evaporation of the soil water from their outer surfaces. Glazed pots also permit a more definite control of the amount and distribution of the soil moisture. Their use provides soil conditions more nearly like those existing in the field.

The fertilizer which was used was made from borax-free commercial salts —sodium nitrate, acid phosphate and potassium sulfate—containing, respectively, 18.96 per cent of ammonia, available phosphorous equivalent to 18.00 per cent of phosphoric oxide, and 49.68 per cent of potassium oxide. This was applied in 4–8–6 proportions on the basis of 2000 pounds of mixed fertilizer per acre for the potatoes and at the rate of 500 pounds per acre for corn and beans. The sodium nitrate was ground in a mill to insure more thorough mixing with the phosphate and sulfate.

The amount used per pot was computed from the amount which would be applied in the field in drills 33 inches apart, the length of drill corresponding to the diameter of the pot. Thus 29.98 gm. of the mixed fertilizer per pot was used for the potatoes and 5.15 gm. for the beans and corn. The required portions were weighed separately into small bottles.

Definite amounts of borax were then added to the borax-free fertilizer. The "20 Mule Team" commercial brand which contained 67.2 per cent of anhydrous borax was added at the rates shown in the table on the following page.

The borax was not mixed with the ulbk fertilizer but was weighed for each pot, added to the above-mentioned bottles and mixed with the fertilizer by shaking. No borax was added to the fertilizer which was used in the check pots and neither borax nor fertilizer was added to those designated as controls. Unless otherwise stated all tests were made in triplicate; that is, there were 3 pots of potatoes, corn or beans for each treatment in each series listed.

[2] The writers wish to acknowledge their indebtedness to J. M. Bartlett, chemist of the Maine station, for analyses of the materials used for the fertilizers and to C. H. Jones, chemist of the Vermont station, for similar assistance and more particularly for making tests for borax in leaves and other plant parts.

RATE PER ACRE OF ANHYDROUS BORAX	WEIGHT OF THE "20 MULE TEAM" BRAND APPLIED	
	Per $5\frac{1}{2}$-inch pot	Per 8-inch pot
pounds	*gm.*	*gm.*
1	0.0193	0.2806
2	0.0386	0.5613
4	0.0772	
5	0.0965	0.1403
6	0.1158	
8	0.1544	
10	0.1930	0.2806
20	0.3860	0.5613

The Green Mountain variety of potatoes was used for the tests. Unblemished tubers of uniform size were selected and sliced lengthwise, each seed-piece weighing from 4 to 6 ounces. Eleven and one-half pounds of soil were added to each 8-inch pot and one seed-piece was planted, with cut portion down, after which 5 pounds of soil were added, making the seed-piece about 3 inches below the surface of the soil. In those series in which the fertilizer was applied in drills it was shaken out of the bottles through a perforated aluminum cap and evenly distributed over a strip about 3 inches wide across the diameter of the pot. When applied in drills a layer of soil about $\frac{1}{4}$ inch thick was spread between it and the seed-piece. When broadcasted it was mixed with a given quantity of soil. This could be done quite thoroughly as the soil was nearly air-dry.

The Bush Horticultural variety of beans and the Leaming dent variety of corn were used. These lots of seeds gave germination tests of 100 and 94 per cent, respectively. Five seeds per pot were planted at a depth of 1 inch and seedlings appearing after the first three were removed. Five and one-half pounds of soil was first added to each $5\frac{1}{2}$-inch pot, the seeds planted with uniform spacing over a strip 3 inches wide and then covered with $\frac{3}{4}$ pound of soil. The fertilizer was applied in the same manner as described for potatoes, with a thin layer of soil between it and the seed.

In order that the soil might be watered from the bottom as well as from the top a cardboard tube about $1\frac{1}{2}$ inches in diameter was set against the vertical wall of each pot. After dipping these tubes in hot paraffin they became water-tight and no evaporation took place from them. About two-thirds of the initial water, added to the soil, was introduced through the tubes from measured flasks. The remainder was added with a sprinkling can and the final weight of the pots recorded. Except where specifically stated 19.2 per cent of water was maintained in the soil of all pots, this being 50 per cent of its water-holding capacity, previously determined.

Water was added to restore the amount lost as shown by a decrease in the weight of the pots. After the plants became fairly large this was done each day. An estimated allowance was made for the increase in pot weights due to the green matter of the plants. This estimate was found to be fairly close

to the green weights of the plants at the time of harvesting. After harvesting the plants, three of the bean and two of the potato pots, selected at random, were found to have soil moisture contents of 19.1, 21.3, 18.9, 15.9 and 16.7 per cent, respectively. This shows that the variation from the desired 19.2 per cent was not excessive. The moisture appeared to be evenly distributed throughout the soil in each pot.

During the germination period and until the plants became uneven in size, one-half of the water was added to the bottom of the soil through the paraffined tubes and one-half was added to the surface of the soil. After the pots began to require very unequal amounts of water it was all added to the surface soil.

From the time of planting, February 2, to that of harvesting, April 22, the nightly and daily temperatures of the greenhouse averaged 58.0° and 68.5°, respectively. The average relative humidity was 57.3 per cent and the hours of sunshine were 42.8 per cent of the total possible amounts.

After plants appeared above ground, detailed notes on the growth and appearance of each were made every 7 to 10 days. The photographs of representative pots and the crop-weight averages are of plants which grew in the one that most nearly represented the average of the triplicately treated pots.

EFFECT OF BORAX UPON THE GROWTH OF POTATOES

For potatoes the borax applications per pot were at the rate of 2, 5, 10 and 20 pounds of anhydrous borax per acre. The applications of fertilizer, with and without borax, were made in drills below the seed-piece (series 1); in drills above the seed-piece (series 2); mixed with the second 3 inches of soil (series 3) and mixed with the first, or top 3 inches of soil (series 4). Series 5 received fertilizer and borax at the rate of 5 pounds per acre in drills below the seed-piece together with additions of either ground limestone, hydrated lime, gypsum or manure at the rates of 2,000, 1,000, 1,000 and 20,000 pounds per acre, respectively. Series 6 was similar to series 5 except that borax was used at the rate of 10 pounds per acre. The water content of the soil was maintained in the manner given under the section on experimental procedure.

Foliage abnormalities and injuries[3]

Plants were showing in nearly all of the pots a month after the seed-pieces had been planted. At that time, March 4, certain abnormalities were noted in most of the plants growing in pots to which borax had been added at the rates of 10 and 20 pounds per acre. In some cases the young plants appeared

[3] For a description of the types of injury to potatoes as observed in the field and in the greenhouse by one of the writers, where commercial fertilizers containing borax were used, the reader is referred to Bulletin 288 of the Maine Agricultural Experiment Station (12, p. 95–101, 107–118).

to be stunted, dwarfed and generally of a lighter green color than the checks. In other cases they looked normal except for an upward curling of the terminal leaflets of some of the lower leaves, accompanied by death of the leaflet margins especially at the tips. A week later those plants which were light green and stunted had become more nearly normal in color. They always remained in a stunted condition, however, and began to show a type of injury which appeared to be most typical for the potato plant.

This injury appeared on many of the plants which at first seemed perfectly healthy, and consisted in its first stages of death of the margins of the leaves, especially at the tips of the margins of the terminal leaflets of the oldest leaves. This was soon followed by a change in color of the entire leaflet to a greenish or golden yellow which then spread throughout the entire leaf as may be noted in pot 57 (pl. 1, fig. 1). If badly affected, the leaf died and fell off. Where injury was excessive this process moved upward until most of the leaves had fallen off, while all of them were badly injured, as may be noted in pot 60 (pl. 1, fig. 3) to which borax had been added at the rate of 20 pounds per acre in the upper 3 inches of soil. When the upper leaves became affected, however, they did not change to a golden color, and often dead areas, similar to the marginal injury, appeared in the interior, surrounded by somewhat less injured tissue. Plate 1, figure 2, from left to right, shows a normal leaf, one slightly injured, and one with killed marginal tissue and golden yellow interiors, the final death stage of which would be like the two leaves at the right. The third and fourth leaves from the right are from the upper part of a badly affected plant like that of pot 60 (pl. 1, fig. 3). Pot 56 (pl. 1, fig. 1) received borax at the rate of 10 pounds per acre mixed with the upper 3 inches of soil and shows plants (photographed March 29) which have been stunted as compared with the normal plants in pot 73. Pot 13 of plate 1, figure 3, which received borax at the rate of 20 pounds per acre (photographed April 22), shows an even more pronounced case of stunting as well as leaf injury caused by borax. The plants of pot 25, which received half as much borax as pot 13, grew well and appeared normal at first but later became quite badly affected, as may be noted in the photograph.

Effect of method of application

The photographs reproduced in plates 2 and 3 were taken March 9 and show all of the pots of series 1, 2, 3 and 4, the borax applications from right to left being at the rates of 0, 2, 5, 10 and 20 pounds per acre. At that time the manner of applying the borax-fertilizer mixture was beginning to show a marked effect. At that stage of growth, the applications in drills below the seed-pieces (series 1, pl. 2, fig. 1) were much more toxic than in drills above (series 2, pl. 2, fig. 2). In the same way plate 3 shows that the applications to the 3 inches of soil below the seed-pieces (series 3, fig. 1) caused more retardation and injury than those to the upper 3 inches of soil (series 4, fig. 2).

Moreover, of the applications below the seed-pieces, those in drills caused more toxicity than those which were broadcasted. It was also apparent from the checks that the borax-free fertilizer did not give as good results when applied below as when applied above the seed-pieces, but this difference disappeared later. As may be noted from these photographs, a number of the plants of the 10 and 20-pound borax lots in series 2 and 4 appear nearly normal. Later, however, they developed the characteristic lower leaf injury.

In general, there was a pronounced increase in injury in passing from the 5 to 10-pound borax pots. The plants in the two pots showing in the foreground of the photograph of series 1 were the only ones of the checks, the 2-pound and the 5-pound borax lots which did not develop well.

Horizontal views of representative pots of the 4 series were photographed on March 29 and are shown in plate 4 and in figure 1 of plate 5. A decided decrease in the size of the plants of the 10- and 20-pound borax pots is evident where the fertilizer was applied in drills below the seed-pieces (pl. 4, fig. 2) as well as when broadcasted in the second 3 inches of soil (pl. 4, fig. 3). The plants are more even in size in the pots in which the fertilizer was applied above, either in drills (pl. 4, fig. 1) or when mixed with the upper 3 inches of soil (pl. 5, fig. 1). This last-mentioned figure shows that the lower leaves had become badly affected where borax had been applied at the rates of 10 and 20 pounds per acre. The 5-pound borax lot also was slightly affected. At first this lower leaf injury was least marked in the series in which the fertilizer had been applied in drills above the seed-pieces, but it developed later to a considerable extent.

Relative amounts of leaf injury at the time of harvesting

During the two weeks previous to the harvesting the plants did not grow to any appreciable extent, nor was there much increase in borax injury. At the time of harvesting practically no lower leaf injury was noted on the plants of the 2-pound borax lots, and only a slight amount in those of the 5-pound lots. For a given series there was not much difference, on the average, in the amount of injury caused by the 10 and 20-pound applications. A general stunting of the plants was most marked where the fertilizer had been applied in drills below (series 1). Series 4, in which the fertilizer had been mixed with the upper 3 inches of soil, showed the most leaf injury and some of the plants, as in pot 60 (pl. 1, fig. 3), had lost most of their leaves, while those remaining were dry, crisp and practically dead.

Foliage and tuber weights

Tables 1 and 2 give the dry weights of the tops for the triplicate treatments and the green weights of the tubers which developed. These figures may be more readily compared in table 3 which shows the weights, relative to the

checks, which are given a value of 100. These values are based on the average of weights given in tables 1 and 2.

It is well known that individual seed-pieces give very uneven yields, even when obtained from the same hill of potatoes. Consequently, irregularities may be expected in these tests since the seed-pieces were halves of potatoes

TABLE 1

The dry weights of foliage and green weights of tubers of potato plants grown in pots to which fertilizer and definite amounts of borax were added

	CHECK, NO BORAX		2 POUNDS OF BORAX		5 POUNDS OF BORAX		10 POUNDS OF BORAX		20 POUNDS OF BORAX	
	Tops	Tubers	Tops	Tubers	Tops	Tubers	Tops	Tubers	Tops	Tubers
Series 1. Borax-fertilizer mixtures in drills below the seed-pieces										
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
Pot 1............	15.68	415.0	21.89	436.0	15.04	241.0	5.80	94.5	*	85.0
Pot 2............	20.90	0	21.14	287.0	12.81	232.0	21.30	222.0	6.43	54.5
Pot 3............	5.66	426.0	10.18	17.0	10.44	298.5	1.54	0	7.80	11.5
Average.......	14.08	280.3	17.70	297.7	12.76	291.5	9.54	105.5	7.11	50.3
Series 2. Borax-fertilizer mixtures in drills above the seed-pieces										
Pot 1............	18.53	455.0	16.03	393.0	23.42	382.0	9.60	276.0	11.57	173.5
Pot 2............	18.39	581.0	14.86	272.0	11.55	170.0	18.84	307.0	11.59	280.0
Pot 3............	9.63	263.0	13.75	426.0	11.63	322.0	17.30	158.0	10.79	270.0
Average.......	15.52	433.0	14.88	397.0	15.53	291.3	15.24	247.0	11.44	241.2
Series 3. Borax-fertilizer mixtures in the second 3 inches of soil										
Pot 1............	17.04	185.5	9.28	192.0	16.63	299.0	3.14	390.0	2.66	41.5
Pot 2............	19.50	396.0	7.92	348.0	11.19	406.0	18.72	326.0	5.58	81.5
Pot 3............	12.53	233.0	12.64	312.0	18.12	313.0	22.70	253.5	6.24	80.0
Average.......	16.36	271.5	9.95	284.0	14.65	339.3	14.89	323.2	4.83	67.5
Series 4. Borax-fertilizer mixtures in the first 3 inches of soil										
Pot 1............	18.30	523.0	14.45	238.5	11.68	296.0	10.75	185.5	11.81	301.0
Pot 2............	14.69	251.5	14.88	360.0	18.34	316.0	6.38	64.5	5.88	155.5
Pot 3............	13.88	365.5	15.46	291.5	14.56	358.0	5.91	186.0	5.66	101.0
Average......	15.62	380.0	14.93	296.7	14.86	323.3	7.68	145.0	7.78	185.0

* Used for chemical determinations.

selected from a large number to obtain tubers which were unblemished and even in size. It is evident, nevertheless, that there is a considerable decrease in tuber weight where borax was added at the rate of 10 pounds per acre, except in series 3 (table 3). Where the borax applications were at the rate of 20 pounds per acre there was a marked decrease in every case, especially where the applications were below the seed-pieces (series 1 and 3), in which

the yield averaged 22 per cent of that given by the checks. Where the applications were above the seed-pieces (series 2 and 4) the corresponding average yield was 53 per cent of that given by the checks. The dry weights of tops are more variable but do not show any marked decrease in the 2 and 5-pound borax lots. Considerably decreased weights are evident in some of the 10-pound and in all of the 20-pound lots. In the latter case the weights are lowest where the borax-fertilizer mixture was applied below the seed-pieces. In general, foliage and tuber weights correlate with the above described borax injury, which was based upon notes taken while the plants were growing.

TABLE 2

The dry weight of tops and green weight of tubers of potato plants grown in pots to which ground limestone, hydrated lime, gypsum or manure had been added in addition to the borax-fertilizer applications

	GROUND LIMESTONE				HYDRATED LIME				GYPSUM				MANURE	
	In drills		In upper 3 inches		In drills		In upper 3 inches		In drills		In upper 3 inches		In upper 3 inches	
	Tops	Tubers	Tops	Tubers	Tops	Tubers	Tops	Tubers	Tops	Tubers	Tops	Tubers	Tops	Tubers
Series 5. Fertilizer and 5 pounds per acre of borax in drills below the seed-piece														
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Pot 1	18.07	297.5	7.51	66.5	9.68	230.0	8.21	180.0	18.78	526.0	lost	187.0	15.36	245.0
Pot 2	18.55	342.0	23.12	344.0	13.99	379.5	8.54	131.0	0	0	5.76	106.0	13.50	223.0
Pot 3	17.86	583.0	19.50	248.0	9.47	0	12.76	210.0	11.18	215.5	7.80	83.5	14.11	247.5
Average	18.16	407.5	16.63	219.5	11.05	203.2	9.84	174.0	9.99	247.2	6.78	125.5	14.32	238.5
Series 6. Fertilizer and 10 pounds per acre of borax in drills below the seed-piece														
Pot 1	2.08	5.0	4.46	23.0	17.97	289.0	13.13	271.5						
Pot 2	21.96	433.0	9.79	62.5	18.77	371.5	13.41	142.0						
Pot 3	12.38	361.0	16.87	271.0	17.13	298.0	13.57	296.0						
Average	12.14	266.3	7.34	118.8	17.98	286.2	13.37	236.5						

Effect of borax upon the roots of potatoes

The root systems and yields of representative pots from the four series, discussed above, are shown in figure 3 of plate 5 and in the figures of plate 6. It may be seen that the root systems and tuber yields are smaller from the 10 and 20-pound borax applications, with the exception of the 10-pound applications of series 3, pot 41 (pl. 6, fig. 3). Table 3 also shows that the average weights for that treatment were much like those of the checks.

The browned tips of decayed roots were evident in the 10 and 20-pound lots of some of the pots of series 1 and 4. In cases of severe injury as in pot 60 (pl. 1, fig. 3) the stems both above and below the surface of the soil were soft and tough, with occasional brown-colored lesions on the underground portions. In general, however, injuries due to borax were not as much in evidence on the underground parts as on the aerial portions of the potato plants grown in pots in the greenhouse.

Effects of using lime, gypsum and manure with borax-fertilizer mixtures

Table 4 gives the weight values, relative to the checks, resulting from the addition of either finely ground limestone, hydrated lime, gypsum or manure at the rate of 2,000, 1,000, 1,000 and 20,000 pounds per acre, respectively. The lime applications were with borax-fertilizer mixtures applied in drills below the seed-pieces. Thus the 5-pound-per-acre borax pots of series 1 constitute the checks for series 5 (table 4), while the 10-pound borax pots of series 1 are the checks for series 6. A photograph (pl. 5, fig. 2) taken 25 days before the plants were harvested shows that the toxic effect of borax added at the rate of 10 pounds per acre (pot 10) was considerably neutralized by mixing it either with hydrated lime (pot 88) or with a finely ground limestone (pot 84). Pot 62 which received ground limestone mixed with fertilizer and borax at the rate of 5 pounds per acre looked somewhat better than the corresponding unlimed pot no. 9. No benefit was observed where gypsum (pot 69) was applied; nor did the manure cause much effect other than a

TABLE 3

Weights of tubers and of tops relative to the checks, which are given a value of 100; based on the averages given in table 1

BORAX APPLIED PER ACRE	IN DRILLS BELOW (SERIES 1)		IN DRILLS ABOVE (SERIES 2)		IN SECOND 3 INCHES (SERIES 3)		IN FIRST 3 INCHES (SERIES 4)	
	Tubers	Tops	Tubers	Tops	Tubers	Tops	Tubers	Tops
lbs.								
0	100	100	100	100	100	100	100	100
2	106	126	92	96	105	61	78	96
5	104	90	67	100	125	90	85	95
10	38	68	57	98	119	91	38	49
20	18	51	56	73	25	29	49	50

more sustained growth rate during the one or two weeks before the time of harvesting.

The relative dry weights (table 4) are in accord with the notes taken during the growing season and show that, in general, lime neutralized some of the toxicity of borax when the latter was applied at the rate of 10 pounds per acre; while neither lime, gypsum nor manure exerted any appreciable effect when used with borax applied at the rate of 5 pounds per acre. However, borax at the rate of 5 pounds per acre was practically non-toxic and hence the possible effect of gypsum and of manure was not conclusively tested in this experiment.

Results obtained with a commercial fertilizer containing borax[4]

A few pots were fertilized with a commercial fertilizer which contained somewhat less than 1 per cent of borax. Where the applications were at

[4] This is the same fertilizer as is listed as "Station No. 5549" on page 105 of Bulletin 288 of the Maine Agricultural Experiment Station (12).

the rates of 2000 and 1000 pounds per acre the same types of injury were observed as developed in the plants of the pots to which borax was added. The number of pots containing this commercial fertilizer was not sufficient, however, to make a comparison of yields or extent of injury with the borax-treated pots.

Borax has been reported as present in the injured portions of leaves of plants grown in pots containing fertilizers which carried this material in varying amounts, but not in the leaves of plants grown on a borax-free fertilizer of a similar composition (12). Similar samples were collected from pots containing the commercial fertilizer mentioned above and from pots containing the basal fertilizing mixture used in these experiments, with and without borax. These were tested by C. H. Jones. Borax was found in the injured leaves from those pots where it was introduced with the fertilizer but not in the leaves from the pots which received the basal mixture alone.

TABLE 4

Weights of tubers and tops relative to the checks which are given a value of 100; based on the averages in table 2

	5 POUNDS OF BORAX PER ACRE (SERIES 5)		10 POUNDS OF BORAX PER ACRE (SERIES 6)	
	Tubers	Tops	Tubers	Tops
Checks—borax-fertilizer mixture only	100	100	100	100
Ground limestone in drills	139	142	25	127
Ground limestone in first 3 inches	75	130	113	77
Hydrated lime in drills	70	87	271	188
Hydrated lime in first 3 inches	60	77	224	140
Gypsum in drills	85	78		
Gypsum in first 3 inches	43	53		
Manure in first 3 inches	82	113		

Summary relative to the effect of borax upon potatoes

The application of 2 pounds of borax per acre caused no injury to potato plants while a few of the plants to which 5 pounds per acre were added exhibited a slight injury to the lower leaves.

The additions of 10 and 20 pounds of borax per acre caused a marked injury and retardation, especially when applied below the seed-pieces.

In general the toxic limit of borax for potatoes under the conditions of the experiment was somewhat above the rate of 5 pounds per acre.

When applied above the seed-pieces there was no noticeable effect on potato foliage when the plants were young; but later they developed excessive leaf injury where borax was present at the rates of 10 or 20 pounds per acre.

Borax-fertilizer mixtures applied below the seed-pieces proved to be the most toxic, particularly when in drills. The plants receiving the heavier applications were stunted from the first and often developed considerable leaf injury also.

The higher borax applications caused considerable injury to root systems and decrease in tuber yields, especially when applied below the seed-piece. Stem injury, both above and below the soil, was most marked where the plants grew normally at first, but were injured later by the borax which had been applied above the seed-piece.

Both finely ground limestone and hydrated lime appeared to neutralize some of the toxicity of borax when applied in drills below the seed-piece at the rate of 10 pounds per acre.

Plants grown in pots fertilized with a commercial fertilizer containing borax developed the same types of injury as occurred where borax-fertilizer mixtures were applied. Boron was found to be present in the affected leaves in both cases.

THE EFFECT OF BORAX UPON THE GROWTH OF CORN

With corn the fertilizer-borax mixtures were applied to the soil in three different ways. Series 1 designates the application in drills below the seed, series 2 in drills above the seed and series 3 mixed with the upper 3 inches of soil. The rates of application of anhydrous borax were 1, 2, 3, 5, 10 and 20 pounds per acre. The plants listed as checks received fertilizer but no borax and those designated as controls had nothing added to the soil. All fertilizer applications were on the basis of 500 pounds per acre. Additional details relative to fertilization, planting, etc., are given under the section on experimental procedure. As stated before, the various treatments were in triplicate.

The seedling stage

Although the corn used for seed gave a germination test of 94 per cent, it did not germinate as well in the soil. Five seeds were planted per pot and the seedlings appearing after the first three were removed. Table 5 shows the total number of those which appeared in the triplicately treated pots of the three series, the checks and the controls. Fifteen seedlings per treatment should have appeared had the germination been perfect. As the table shows it was not perfect either in the checks or in the controls. However, a marked reduction in the number of seedlings which appeared is evident in the 5, 10 and 20-pound-per-acre borax applications in drills below the seed (series 1); and in the 20-pound applications both in drills above and when broadcasted in the upper 3 inches of soil.

By April 2, or 24 days after planting, all except one of the seedlings which appeared in the 5, 10 and 20-pound borax pots of series 1 had died. In series 2 and 3 all seedlings had died in the pots to which fertilizer and borax at the rate of 20 pounds per acre had been added. All of the seedlings in the 10-pound borax treated pots of these two series were stunted and a few of them died.

Some of the seedlings were bleached to a yellowish or whitish tinge from the time of their appearance above the soil. Others looked nearly normal at

first but rapidly turned white and died. Retardation of germination due to borax did not appear to be as marked as with beans but the young seedlings seemed to be more sensitive toward borax. As far as could be observed the death of the seedlings was not due to any influence other than that of borax.

It was readily apparent that the borax-fertilizer mixtures were most toxic when applied in drills below the seed and least toxic when mixed with the upper 3 inches of soil. Moreover, the fertilizer itself appeared to have a depressing effect upon the young corn plants when applied in drills, particularly drills below the seed. This was evident from the uneven stand and irregular growth obtained in series 1 and 2 as compared with the much more even stand and growth obtained in the broadcasted series no. 3. Plants in the control pots (no addition to the soil) grew faster than those in the checks (borax-free fertilizer added), but soon fell behind and developed excessive malnutrition characteristics.

TABLE 5

Effect of different borax-fertilizer mixtures on the germination of corn

POUNDS OF BORAX PER ACRE	IN DRILLS BELOW (SERIES 1)						IN DRILLS ABOVE (SERIES 2)						IN FIRST 3 INCHES (SERIES 3)						NO ADDITION TO SOIL
	0	1	2	5	10	20	0	1	2	5	10	20	0	1	2	5	10	20	
Seedlings per pot 1........	3	1	2	1	1	0	2	0	3	4	2	0	2	4	3	3	0	2	5
Seedlings per pot 2........	3	2	4	0	0	0	3	3	1	2	2	0	4	5	5	4	5	1	3
Seedlings per pot 3........	3	4	5	2	2	2	3	3	4	2	2	1	5	3	5	3	4	2	3
Total per treatment.......	9	7	11	3	3	2	8	6	8	8	6	1	11	12	13	10	9	5	11

Nature of borax injury to corn

When young corn plants were injured by borax they generally turned almost white and died. The roots of such plants were found to be entirely browned and decayed. Plants which attained a height of 6 inches or more before becoming affected, evidenced borax toxicity in their foliage by a banded bleaching of the chlorophyl of the leaves, especially marked at the leaf margins. The extreme tips of the leaves were often killed but not the margins. The banded bleaching was not as pronounced as a general stunting of the plants which survived the higher borax applications. Very young corn plants appeared to be more sensitive toward borax than young bean seedlings while stalks of corn which obtained a normal start appeared to be considerably less sensitive than bean plants in the presence of the same amounts of borax. This comparison could be made, as the corn and beans were planted at the same time under the same experimental conditions. However, the uneven stand in all but series 3 made the tests with corn less conclusive than those with beans.

Effect upon the roots

Figure 2, plate 7, shows the roots of plants from representative pots of series 2 in which the fertilizer was applied in drills above the seeds. The roots of the 1-pound borax pot no. 102 are much like those of the check pot no. 99 while the 2-pound borax application, pot 103, caused a bushy development of fine roots. Besides the reduction in root systems, where larger amounts of borax were applied, the browned ends of killed roots were observed as is shown in the 10-pound borax pot no. 111.

TABLE 6

Dry weights of corn foliage grown in pots to which fertilizer and definite amounts of borax were added

		CHECK, NO BORAX	1 POUND OF BORAX PER ACRE	2 POUNDS OF BORAX PER ACRE	5 POUNDS OF BORAX PER ACRE	10 POUNDS OF BORAX PER ACRE	20 POUNDS OF BORAX PER ACRE
Series 1. Borax-fertilizer mixtures in drills below the seed							
		gm.	gm.	gm.	gm.	gm.	gm.
Weights per pot	1......	17.68	0.00	21.46	0.00	0.00	0
	2......	20.50	11.72	8.37	0.00	0.00	0
	3......	9.74	19.06	22.16	0.00	15.02	0
Average..............		15.97	10.26	17.33	0.00	5.00	0
Series 2. Borax-fertilizer mixtures in drills above the seed							
Weights per pot	1......	10.93	0.00	16.06	17.32	4.28	0
	2......	13.13	9.00	8.74	0.00	0.00	0
	3......	14.45	14.07	20.67	10.74	2.28	0
Average..............		12.84	7.69	15.16	9.35	2.19	0
Series 3. Borax-fertilizer mixtures broadcasted in first 3 inches of soil							
Weights per pot	1......	4.33	13.16	18.06	11.43	2.99	0
	2......	13.75	14.20	13.16	9.41	9.93	0
	3......	8.19	14.45	13.87	11.45	6.54	0
Average..............		8.76	13.93	15.03	10.86	6.49	0

Where the borax fertilizer mixtures were mixed with the upper 3 inches of soil (series 3) the roots of the 1 and 2-pound pots (pl. 8, fig. 2) appear like those of the check pot no. 116; those of the 5-pound pot no. 125 show the bushy development mentioned above, while considerable stunting and injury is evident in those of the 10-pound pot no. 127.

Dry weights of foliage

Table 6 gives the dry weights in grams of the foliage obtained from series 1, 2 and 3. In table 7 the average weight for each triplicate treatment is compared with that of the checks, which are given a value of 100. Too much

emphasis should not be placed upon these weights because of the large differences between triplicates, due to the uneven stand and growth of the corn. However, the differences caused by borax are very great and it is readily apparent from table 7 that the 10-pound applications caused a marked reduction in all cases, particularly in series 1 and 2; while the 20-pound application permitted no growth beyond the seedling stage.

Evidence of possible stimulation of corn plants due to borax

If the dry weights of series 3 alone are considered there is strong evidence of a marked stimulation of growth where borax was added at the rates of 1, 2 and 5 pounds per acre. A photograph of tops (pl. 8, fig. 1) taken at the time the plants were harvested on April 11, shows that the plants in pots 118 and 123 are larger than those in the check pot no. 116. Likewise the photograph of series 2 (pl. 7, fig. 1) exhibits an evident stimulation in the 1, 2 and 5-pound borax pots. But, according to the dry weights obtained, it is misleading in that respect (table 6) because the plants failed to grow in one of the pots with a 5-pound, as well as in one with a 1-pound borax application.

TABLE 7

Dry weights of corn foliage relative to the checks which are given a value of 100; based on the averages given in table 6

BORAX APPLIED PER ACRE	SERIES 1, IN DRILLS BELOW	SERIES 2, IN DRILLS ABOVE	SERIES 3, IN UPPER 3 INCHES
lbs.			
0	100	100	100
1	64	60	159
2	113	118	173
5	0	73	124
10	32	17	74
20	0	0	0

Although the growth in series 3 was much more uniform for a given treatment, the checks were smaller than those of the drilled series. Thus, when the three series are compared the evidence of a stimulating effect of borax seems to be rather doubtful. Since borax was always applied together with fertilizer the conditions of the experiment did not give much opportunity for borax stimulation to manifest itself. It is of interest to note that the broadcasted series of both the beans and the corn were alike in two respects. The dry weights of the foliage of the check plants were less than those of the checks of the drilled series, although the growth was more even than in the drilled series. Also, the dry weights from pots with low borax applications were considerably greater than those from the checks.

Results obtained with corn from adding lime, gypsum or manure to the borax-fertilizer mixtures

Hydrated lime, gypsum and well rotted manure were used with borax-fertilizer mixtures to determine whether or not they had a neutralizing or antagonizing action against borax injury to corn. Applications were at the rates of 1000, 1000 and 10,000 pounds per acre, respectively. The dry weights obtained are given in table 8. In series 4 the above materials were added with fertilizer and 5 pounds per acre of borax in drills below the seed. Thus the 5-pound borax pots of series 1 (table 6) constitute the checks for series 4. All of these check plants died. Therefore, if the death of the plants of the 5-pound borax pots of series 1 was caused entirely by the borax, as all observations indicated, then the growth obtained in series 4 must be attributed to the antagonizing effect of the lime, gypsum and manure. In series 5, where the borax applications were at the rate of 10 pounds per acre, the effect of lime only was tested; and as all of the plants except one died in the pots used as checks in series 1, the growth obtained in series 5 must again be attributed to the antagonistic effect of the lime against borax injury.

TABLE 8

The dry weights of corn foliage obtained when either hydrated lime, gypsum or manure was added to borax-fertilizer mixtures

	HYDRATED LIME		GYPSUM		MANURE
	In drills	In first 3 inches	In drills	In first 3 inches	In first 3 inches
Series 4. Fertilizer and 5 pounds of borax per acre in drills below					
	gm.	gm.	gm.	gm.	gm.
Weight per pot 1..	7.86	11.31	3.08	9.82	4.66
Weight per pot 2..	8.65	0.00	13.08	0.00	11.41
Weight per pot 3..	9.72	7.44	9.70	10.55	13.37
Average..........	8.78	6.25	8.62	6.79	9.81
Series 5. Fertilizer and 10 pounds of borax per acre in drills below					
Weight per pot 1..	3.87	0.00			
Weight per pot 2..	13.37	0.00			
Weight per pot 3..	11.30	6.99			
Average..........	9.51	2.33			

Although characteristic stunting and banded bleaching were apparent in nearly all of the plants which grew in series 5, those of series 4 looked very nearly normal, especially in the manured pots.

Better growth was obtained in series 4, and particularly in series 5, where the lime was mixed directly with the borax-fertilizer mixtures, instead of with the upper 3 inches of soil. This was true also in similar treatments with beans, and indicates that the borax was converted into an insoluble and hence harmless calcium compound.

The results obtained with corn from using a commercial fertilizer containing borax[5]

The commercial fertilizer which was used contained somewhat less than 1 per cent of soluble boron compounds calculated as anhydrous borax and was applied in drills below the seed at the rates of 2000, 1000 and 500 pounds per acre. These applications are comparable to the 20, 10 and 5-pound borax applications in series 1 and the results obtained were much like those in series 1, as all of the plants which appeared soon died, with the exception of one plant in one of the pots to which the fertilizer was applied at the rate of 500 pounds per acre. This surviving plant was stunted and showed the characteristic banded bleaching.

Conclusions relative to the effect of borax upon corn

Corn plants appear to be particularly sensitive to borax when young but more resistant when older.

For this reason the toxic limit of borax for corn depends largely upon the method of application. The tests recorded above show that borax-fertilizer applications below the seed are much more liable to be toxic than those above or those which are mixed with the surface soil.

It was apparent that the application of 1 and 2 pounds per acre of borax was not harmful. The evidence indicates that 5 pounds is the largest amount of borax per acre that can be used on corn and that, even at this rate, injury may occur when the material is applied in drills below the seed.

The 10 and 20-pound treatments were toxic, under the conditions of these tests, and caused most of the seedlings either to fail to appear or to turn white and die. The few which grew were stunted and exhibited banded bleaching.

Lime and gypsum as well as manure appeared to neutralize some of the toxic effects of borax.

The results obtained from using a ready-mixed commercial fertilizer containing borax were much the same as those resulting from the use of borax-fertilizer mixtures made from tested chemicals.

EFFECT OF BORAX UPON THE GROWTH OF BEANS

The amount and methods of application of fertilizer and borax to beans were the same as are described for corn on page 83.

The seedling stage

Ten days after the beans had been planted (February 5) many of the plants in the 0 (checks), 1 and 2-pound-per-acre borax lots were about 3 inches high,

[5] The same fertilizer as was used for potatoes (p. 83).

those in the 5-pound borax lots were smaller, and none had appeared in the pots containing borax at the rates of 10 and 20 pounds per acre. Later a few seedlings appeared in the highest two borax applications but they were of a yellowish, sickly appearance. If the affected cotyledons were finally drawn out of the soil they often remained incrusted with the seed-coat and did not open. This effect upon germination is best shown in table 9, which gives the total number of seedlings appearing previous to March 1. Since 5 seeds were planted in each pot a total of 15 per treatment indicates perfect germination. The effect of increasing amounts of borax is apparent in series 3 in which the borax-fertilizer mixtures were broadcasted and mixed with the upper 3 inches of soil. It is especially striking in the drilled series no. 1 and 2 in which no growth appeared in the 20 and very little in the 10-pound lots of borax.

Since all seedlings were removed that appeared after the first three, an opportunity was given to examine the roots of those showing borax injury in their aerial parts. Invariably the tap-roots were found to be destroyed and often also the tips of some of the larger laterals.

TABLE 9

Total number of bean seedlings which appeared where borax-fertilizers mixtures were applied in drills below (series 1); in drills above (series 2); and mixed with the first 3 inches of soil (series 3)

POUNDS OF BORAX PER ACRE		SERIES 1						SERIES 2						SERIES 3						NO ADDITION TO SOIL
		0	1	2	5	10	20	0	1	2	5	10	20	0	1	2	5	10	20	
Seedlings per individual pot	1.........	4	5	5	2	3	0	5	3	3	4	1	0	5	3	5	4	5	4	4
	2.........	3	4	3	4	0	0	4	4	3	3	1	0	5	5	5	5	5	3	5
	3.........	4	4	3	5	4	0	5	4	5	4	1	0	5	5	5	5	5	4	4
Total per treatment.......		11	13	11	11	7	0	14	11	11	11	3	0	15	13	15	14	15	11	13

Effect of borax upon foliage growth of beans

Although some of the plants in the pots of the highest borax applications in series 3 remained alive until harvested (April 22) they were very much stunted and of a whitish to yellowish appearance. Many of the older leaves fell off. Figure 2 of plate 9 shows these plants in the foreground with the plants of the 10, 5 and 2-pound-per-acre borax lots in the background. A decreasingly abnormal appearance may be clearly seen with decreasing amounts of borax.

The injuries due to borax appeared first on the margins of the first two leaves, particularly the tips. In the larger borax applications the entire leaf soon turned yellow, then white, followed by a killing of the tissues which progressed from the margins inward. New leaves either failed to appear or were very much stunted and almost devoid of chlorophyl. The two lower pots of figure 1, plate 9, illustrate these extreme cases. The two upper pots

show plants in which there is somewhat less injury as evidenced by larger, new leaves containing a small amount of chlorophyl. These correspond to the second row in figure 2. The next row in figure 2 shows still larger new leaves which are bleached only at the tips. The rear row received borax at the rate of 2 pounds per acre and has new leaves which are normal and old leaves which were very slightly killed at their margins. The checks and 1-pound borax lots showed none of the injury described above. Series 1 and 2 exhibited a sharper gradation of borax injury than series 3. Thus, although the checks and the 1 and 2-pound borax lots appeared much the same in all cases, the plants of the 5-pound lot of the drilled series, no. 1 and 2, showed nearly as much injury as those of the 10-pound lot of the broadcasted series no. 3. In a similar way plants of the 10-pound drilled lots were much like those of the 20-pound broadcasted applications. No growth appeared in pots which received 20 pounds of borax per acre in drills. In general the plants of the 5-pound borax lots recovered somewhat but always exhibited considerable injury, particularly on series 1. A photograph taken February 23 shows the 10-pound borax pots of the three series (pl. 10, fig. 1) and demonstrates that borax added in drills below the seed was the most toxic, followed by that added in drills above, while the least ill effects were obtained when it was mixed with the upper 3 inches of soil.

The sprouting roots come into contact with the borax-fertilizer mixture very early when it is applied in drills below, and this checks the growth or kills the plants at an early stage. The observations show that a young plant is especially sensitive to borax. It is also probable that after diffusion of the material the toxic action of the borax was partly inhibited on account of its dilution or by some property of the soil. Thus, by April 2 all of the plants in the 10-pound borax lots of series 1 were dying, except one which had become larger than the others before showing injury. At the time of harvesting it was growing rapidly, had become dark green and had set large pods. Its roots had probably come into contact with considerable borax, as all of the other plants of this pot died when young, and the borax during a period of 2 months had surely become diffused throughout the soil contained within the solid, glazed pot. An equally striking example occurred in one of the pots in which corn had been planted.

By the time that the beans were harvested, the plants which were not too severely injured had produced large, well filled pods. In some cases the chlorophyl of the pods was bleached out, as is easily seen in pot 31 (pl. 11, fig. 3) which received a 10-pound-per-acre borax application in drills below the seed. Pot 51 received the same amount of borax mixed with the upper 3 inches of soil and its plants show less injury, while the plants of pot 10, which received a 5-pound-per-acre borax application, show still less injury.

Representative plants, including their root systems, are shown in plates 12 and 13. In plate 12 the borax applications from right to left are at the rates of 0, 1, 2, 5 and 10 pounds per acre in drills above the seed. In plate

13 the order of the broadcasted borax applications is the same; the photographs show the insignificant growth in the pot containing borax at the rate of 20 pounds per acre.

Effect of borax upon the roots of beans

The plants had begun to ripen slightly when harvested and the root systems showed a marked decrease with increasing amounts of borax above the 2-pound applications. This may be noted in plates 12 and 13, as well as a tendency toward a bushy development of finer roots grown in the presence of 1 and 2 pounds of borax per acre. The decrease in root systems with increasing amounts of borax was accompanied by an increase, relatively, in the number of laterals which had been browned and killed. Cases of slight injury were revealed by the browned and broken tap-roots. The tap-roots also were the most injured portions in the poisoned seedlings which were removed.

Moreover, the root nodules, which were well developed in the checks and 1 and 2-pound borax lots, were markedly reduced in size and number with increasing amounts of borax (pl. 12 and 13).

Dry weights of foliage of beans

The dry weights of the aerial portions of the bean crop are shown in tables 10 and 11. It may be noted that the triplicate determinations check satisfactorily. A comparison of the average dry weights is made in table 12, in which the weights are referred to the checks which are given a value of 100. These figures point out more definitely the injurious effects of borax which were noted during the growing season. Thus the values for the 1 and 2-pound-per-acre borax lots are much alike in the three series. However, there is a marked reduction with the 5-pound borax applications, which averages 46 per cent in the drilled series and 16 per cent in the broadcasted series no. 3. The crops with higher borax applications were practically complete failures.

About 3 weeks before the harvesting there was some evidence of stimulation in the plants of the 1 and 2-pound borax lots. At the time of harvesting appearances of stimulation had disappeared and none, on the average, is shown by the dry weights.

Influence of water content of soil upon the growth of beans in borax-treated pots

The above tests were all conducted with soil at an optimum water content of 19.2 per cent. In order to ascertain somewhat the influence of soil-moisture conditions upon borax injury, two additional series were planted on March 17. The soil of series 8 was held at a moisture content of 15.2 and that of series 7 at 30.4 per cent, equivalent to 40 and to 80 per cent, respectively, of the maximum water-capacity of the soil.

TABLE 10

The dry weights of bean foliage from pots to which fertilizer and definite amounts of borax were added

		Check, no borax	1 pound of borax per acre	2 pounds of borax per acre	5 pounds of borax per acre	10 pounds of borax per acre	20 pounds of borax per acre
Series 1. Borax-fertilizer mixtures in drills below the seed							
		gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Weight per pot	1	25.39	22.86	20.75	*	15.78	0
	2	26.83	26.30	24.43	17.81	0.50	0
	3	*	24.15	22.93	15.88	5.52	0
Average		26.21	24.44	22.70	16.85	7.20	0
Series 2. Borax-fertilizer mixtures in drills above the seed							
Weight per pot	1	23.62	22.36	23.80	7.03	*	0
	2	22.48	23.86	26.10	9.07	0.09	0
	3	25.84	22.90	21.71	14.76	0.80	0
Average		23.98	23.04	23.87	10.29	0.50	0
Series 3. Borax-fertilizer mixtures in upper 3 inches of soil							
Weight per pot	1	Diseased	25.07	25.11	16.67	8.80	0.69
	2	18.07	23.43	21.25	13.97	9.24	0.25
	3	18.83	20.70	21.53	15.78	10.82	0.40
Average		18.50	23.07	22.63	15.47	9.62	0.45

The triplicate control pots (no addition to the soil) gave dry weights of 18.87, 16.82 and 15.45 gm., respectively.

* Used for chemical tests.

TABLE 11

The dry weight of bean foliage obtained when either hydrated lime, gypsum or manure was added to borax-fertilizer mixtures

		Hydrated lime		Gypsum		Manure
		In drills	In upper 3 inches	In drills	In upper 3 inches	In upper 3 inches
Series 4. Fertilizer and 5 pounds of borax per acre in drills below						
		gm.	*gm.*	*gm.*	*gm.*	*gm.*
Weight per pot	1	18.10	18.17	15.89	18.38	0.95
	2	20.13	22.00	11.11	17.55	2.35
	3	18.56	8.10	*	17.95	*
Average		18.93	16.09	13.50	17.96	1.10
Series 5. Fertilizer and 10 pounds of borax per acre in drills below						
Weight per pot	1	12.48	12.02			
	2	15.76	16.26			
	3	15.59	16.56			
Average		14.61	14.94			

As the previous work indicated that the toxic limit for borax was between 2 and 5 pounds per acre, the borax applications for series 7 and 8 were made at the rates of 0, 2, 4, 6 and 8 pounds per acre. Table 13 shows that increasing amounts of borax considerably reduced the total number of seedlings which appeared in series 8. In series 7 in which the water content of the soil was twice as great, the borax applied had no marked effect on germination. The photographs taken 28 days after planting (pl. 11, fig. 1 and 2) show that the characteristic borax injury is also more marked in the series with the drier soil.

TABLE 12

Weights of bean foliage relative to the checks, which are given a value of 100; based on the averages in tables 10 and 11

APPLICATION OF BORAX PER ACRE	NONE IN CHECK	1 POUND	2 POUNDS	5 POUNDS	10 POUNDS	20 POUNDS
Borax-fertilizer mixtures in drills below (series 1)	100	93	87	64	27	0
Borax-fertilizer mixtures in drills above (series 2)	100	97	99	43	2	0
Borax-fertilizer mixtures in top 3 inches (series 3)	100	125	122	84	52	2

TABLE 13

Total number of bean seedlings which appeared in pots of series 7 and 8

POUNDS OF BORAX PER ACRE		SERIES 7, 30 PER CENT OF MOISTURE						SERIES 8, 15 PER CENT OF MOISTURE					
		0	2	4	6	8	4½*	0	2	4	6	8	4½*
Seedlings per individual pot	1	4	4	5	4	5	5	5	3	3	4	3	5
	2	5	5	4	5	2	5	5	3	3	2	1	5
	3	3	5	†	3	5	5	4	4	4	5	1	5
Total per treatment		12	14	12	12	12	15	14	10	10	11	5	15

* A commercial fertilizer used which contained about 1 per cent of borax.
† Lost.

Dry-weight determinations were not made in the case of series 7 and 8, as some of the leaves were used for chemical determinations by Mr. Jones. It was found, quantitatively, that increasing applications of borax not only caused greater leaf injury but also caused a more concentrated accumulation of boron in the leaves, while those of the checks did not contain boron.

Results obtained with beans from the application of a commercial fertilizer which contained borax

In order to ascertain whether the injury obtained with a fertilizer which contained borax was similar to that obtained with a fertilizer to which borax was added, a set of pots were treated with a 4–8–6 commercial fertilizer which

contained about 1 per cent of borax.[6] In the first set, in which the soil-moisture content was 19.2 per cent, pots were treated in duplicate with the commercial fertilizer at the rates of 2000, 1000 and 500 pounds per acre in drills below. These, then, were comparable to the 20, 10 and 5-pound borax applications in series 1. The same type of injury developed in the plants in both cases but it was more pronounced in those of the pots receiving the commercial fertilizer and the corresponding dry weights were less. This fertilizer was applied at the rate of 450 pounds per acre in series 7, of which the soil moisture content was 30.4 per cent, and in series 8, the soil of which contained 15.2 per cent of water. As may be seen in the photographs (pl. 11, fig. 1 and 2) the commercial fertilizer (last row at right) caused more injury than the 4-pound borax lots (third row from left) and nearly as much as the 6-pound lots (fourth row from left). Leaves from the plants where the commercial fertilizer was added contained more boron than those of the 4-pound borax pots. Thus it was evident that borax-fertilizer mixtures were less toxic than a commercial fertilizer containing an equivalent amount of borax. Since more borax accumulated in the leaves in the latter case it seems that this super-toxicity was due not to some deleterious substance other than borax but possibly to a slower dissolving and leaching away of the naturally incorporated borax.

The use of lime, gypsum and manure with borax-fertilizer mixtures for beans

In the bean studies, series 4 received a fertilizer mixture, carrying at the rate of application, 5 pounds of borax per acre in drills below the seed together with an addition of hydrated lime or of gypsum at the rate of 1000 pounds per acre. In one set of pots the calcium salt was mixed with the fertilizer and in the other it was mixed with the upper 3 inches of soil.

As early as February 23 the recorded notes state that lime, particularly when mixed with the fertilizer, was showing a beneficial effect which is readily apparent in a photograph taken March 3 (pl. 10, fig. 2). At the time of harvesting, however, the limed pots of the 5-pound borax lots looked much the same as those which were not limed and the dry weights (table 11) are much alike in both cases.

The early effect of lime added to 10-pound borax lots (series 5) was more marked than in series 4 (pl. 10, fig. 1) where borax was present at the rate of 10 pounds per acre. The limed plants of series 5 continued to show a superiority, in both foliage and roots. Their dry weights (table 11) are more than 100 per cent greater than the comparable unlimed plants of series 1. However, in no case did the lime neutralize more than a portion of the toxicity caused by borax. The neutralizing effect which occurred may have been due to an antagonism between the lime and the borax, but was more probably due to the conversion of the borax into insoluble and hence harmless compounds.

[6] The same as was used on potatoes (p. 83).

Gypsum appeared at first (pl. 10, fig. 2) to render some benefit, but the effect disappeared and is not indicated by the dry weights obtained (table 11).

In the manured pots a number of the plants were attacked by a parasite. The others suffered excessively from borax injury and the results indicated that the manure increased the toxicity of borax.

Conclusions from the tests with beans

Borax applied at the rate of 2 pounds per acre caused no injury to the growth of beans while with a 4-pound application the characteristic injury and stunting of growth was quite marked. Under the conditions of the experiment, therefore, the toxic limit for this plant was in the neighborhood of 3 pounds of borax per acre when applied in drills. When broadcasted the toxic limit was about 5 pounds per acre. Most of the plants in the 10-pound and all of those of the 20-pound-per-acre borax applications either died or failed to appear above the soil.

Young bean plants are especially sensitive toward borax injury. For that reason borax-fertilizer applications in drills, particularly in drills below the seed, are more toxic than broadcasted applications, since the young roots come into contact with dissolved borax earlier and since the borax solution is more concentrated at first, when applied in drills.

Given amounts of borax which were toxic toward germination and growth in soil held at a 30 per cent moisture content were more toxic in soil containing half as much water.

In a comparison of borax-fertilizer mixtures with a commercial fertilizer, containing an equivalent amount of borax, the same type of injury occurred in both cases and the commercial fertilizer was more toxic. Since the leaves in the latter case contained a greater quantity of boron it is believed that the super-toxicity of the commercial fertilizer was not due to some additional deleterious substance, but rather to a slower dissolving and leaching away of the naturally incorporated borax which would cause the young roots to come into contact with borax for a greater length of time.

Hydrated lime neutralized a part of the toxic effect of borax, particularly when mixed and applied in drills with the borax-fertilizer mixtures. The applications of gypsum and manure did not retard the toxicity of borax to any appreciable extent.

GENERAL SUMMARY

Plants were uninjured where fertilizer mixtures made from borax-free chemicals were applied to soil in pots in which potatoes, corn and beans were grown. These crops were injured where the pots contained the same soil and the same fertilizer mixtures in like quantity, provided sufficient amounts of borax were added with the fertilizer. The same types of injury were produced, in somewhat greater degree, when a commercial fertilizer carrying equivalent amounts of borax was applied.

Corn and beans were more suceptible to the injurious effects of borax than were potatoes. Under the conditions of the experiment, anhydrous borax at the rate of 3 pounds per acre was the largest amount that could be applied in drills with safety to beans. The limit for corn is somewhat under 5 pounds, and for potatoes slightly above 5 pounds per acre. Borax applied with the fertilizer below the seed or seed-piece proved more toxic in all cases than where applied above in like manner. Mixing the borax and fertilizer with the soil decreased the injury and slightly raised the amount that could be applied per acre with safety.

Evidence was obtained that applications of lime prevented some of the injury to potatoes. The tests with gypsum and manure were not conclusive with this crop. All three of these materials seemed to reduce the toxic effects on corn. Lime was beneficial with beans, but gypsum and manure did not show any appreciable influence.

The above results were all obtained with soil at an optimum water content of 19.2 per cent. A subsequent test with beans showed that more injury occurred where the soil moisture was maintained at 15.2 per cent than where it was 30.4 per cent.

The only indication of possible stimulation due to the presence of small amounts of boron occurred with corn, but the evidence was inconclusive.

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PLATE 1

FIG. 1. Potato plants photographed March 29. Pots 56 and 57 received borax at the rate of 10 pounds per acre in drills above the seed-pieces. The plants were stunted early in pot 56. They grew normally at first in pot 57 but are beginning to develop excessive leaf injury. The plants of pot 73 have leaves which are normal.

FIG. 2. Potato leaves photographed March 29. A normal potato leaf at the left followed by increasing amounts of injury in the next two leaves and in the last two at the right. The third and fourth leaves from the right are from the upper part of an affected plant.

FIG. 3. Potato plants photographed April 22. Plants in pot 13 (20 pounds of borax per acre in drills below) were stunted while young. Those in pot 25 (10 pounds of borax per acre in drills above) grew normally at first and then developed considerable leaf injury. Leaf injury is excessive in the case of pot 60 (20 pounds of borax per acre mixed with the upper 3 inches of soil).

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PLATE 2

FIG. 1. Potato plants photographed March 9. Triplicately treated pots of series 1 (borax-fertilizer mixtures in drills below the seed-pieces). Borax applications at the rates of 0, 2, 5, 10 and 20 pounds per acre from right to left.

FIG. 2. Potato plants photographed March 9. Plants of series 2 (borax-fertilizer mixtures in drills above the seed-pieces) arranged as in figure 1 above.


SERIES 1
SERIES 2

PLATE 3

FIG. 1. Potato plants photographed March 9. Triplicately treated pots of series 3 (borax-fertilizer mixtures broadcasted in the second 3 inches of soil). Borax applications at the rates of 0, 2, 5, 10 and 20 pounds per acre from right to left.

FIG. 2. Potato plants photographed March 9. Plants of series 4 (borax-fertilizer mixtures in upper 3 inches of soil) arranged as in figure 1 above.


SERIES 3
SERIES 4
2

PLATE 4

FIG. 1. Potato plants photographed March 29. Representative pots from series 2 (borax-fertilizer mixtures in drills above the seed-pieces). Borax applications at the rate of 0, 2, 5, 10 and 20 pounds per acre from left to right.

FIG. 2. Representative plants of series 1 (borax-fertilizer mixtures in drills below the seed-pieces) arranged as in figure 1 above. Photographed on March 29.

FIG. 3. Representative plants of series 3 (borax-fertilizer mixtures broadcasted in second 3 inches of soil) photographed March 29 and arranged as in figure 1 above.


16
20
22
25
28
1
5
7
10
14
32
35
37
42
43

PLATE 5

FIG. 1. Potato plants photographed March 29. Representative pots from series 4 (borax-fertilizer mixtures broadcasted in upper 3 inches of soil). Borax applications at the rates of 0, 2, 5, 10 and 20 pounds per acre from left to right.

FIG. 2. Potato plants photographed March 29. Borax at the rate of 10 pounds per acre in drills below with hydrated lime (pot 88), with finely ground limestone (pot 84) and with fertilizer only (pot 10). Borax at the rate of 5 pounds per acre in drills below, with fertilizer only (pot 9), with finely ground limestone (pot 62) and with gypsum (pot 69).

FIG. 3. Potato roots and tubers from representative pots of series 2 (pl. 4, fig. 1), photographed April 22, arranged as in figure 1 above.

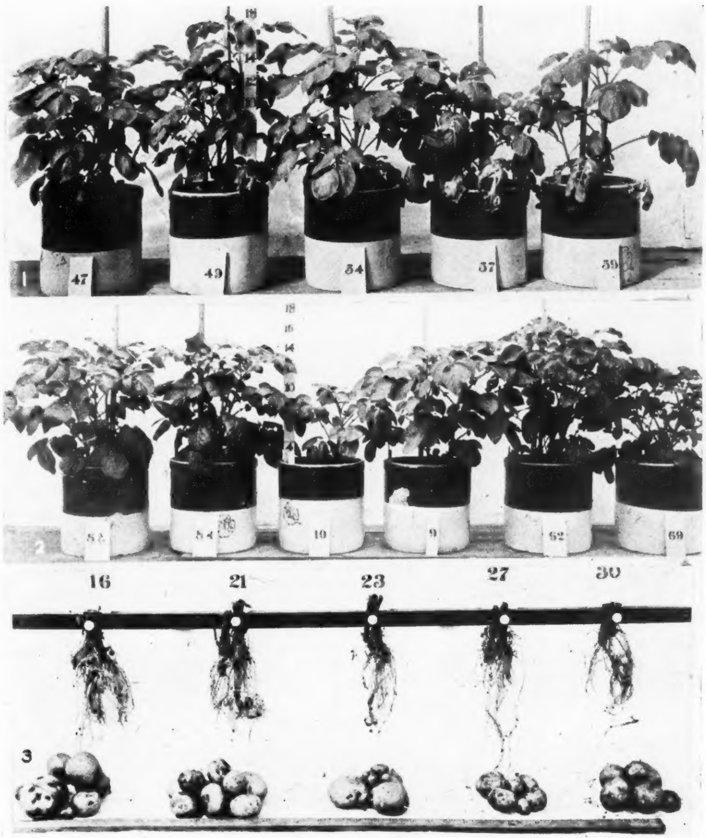
1
47
49
54
57
59
2
19
9
62
69
16
21
23
27
30
3

PLATE 6

FIG. 1. Potato roots and tubers photographed April 22. Representative pots from series 1 (pl. 4, fig. 2). Borax applications were at the rates of 0, 2, 5, 10 and 20 pounds per acre from left to right.

FIG. 2. Potato roots and tubers from representative pots of series 4 (pl. 5, fig. 1) photographed April 22 and arranged as in figure 1 above.

FIG. 3. Potato roots and tubers from representative pots of series 3 (pl. 4, fig. 3) photographed April 22 and arranged as in figure 1 above.

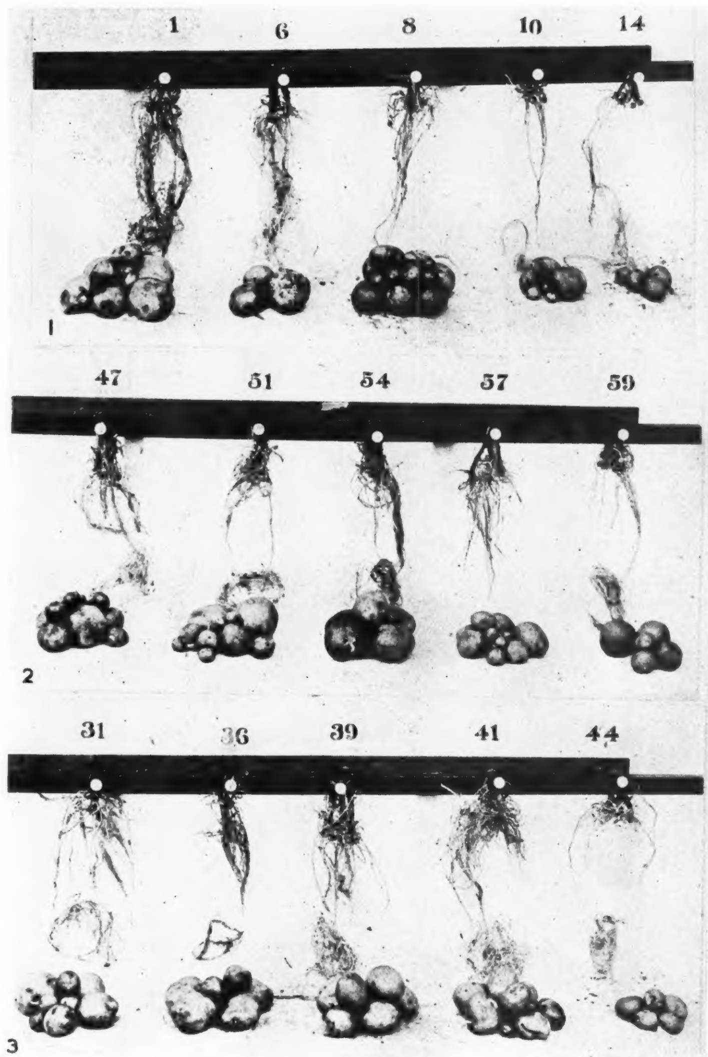
1
6
8
10
14
1
47
51
54
57
59
2
31
36
39
41
44
3

PLATE 7

FIG. 1. Corn plants photographed March 11. Representative pots of series 2 (borax-fertilizer mixtures in drills above the seed). Borax applications at the rates of 0, 1, 2, 5 and 10 pounds per acre from right to left.

FIG. 2. Roots of plants shown in figure 1 above, photographed March 11.

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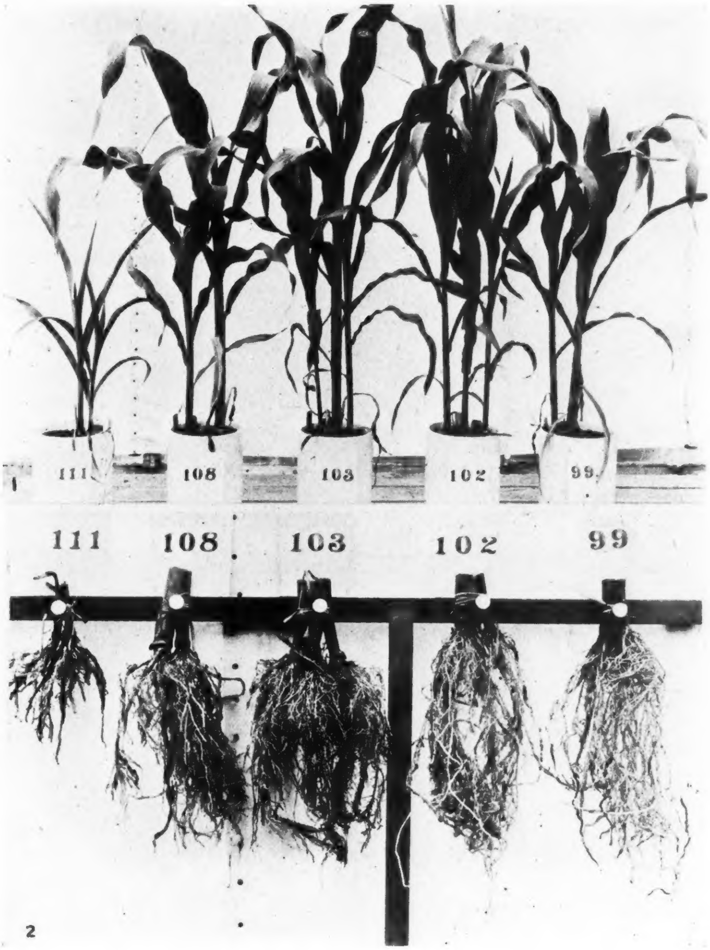

PLATE 8

FIG. 1. Corn plants photographed March 11. Representative pots of series 3 (borax-fertilizer mixtures in upper 3 inches of soil). Borax applications at the rates of 0, 1, 2, 5 and 10 pounds per acre from right to left.

FIG. 2. Roots of plants shown in figure 1 above, photographed March 11.

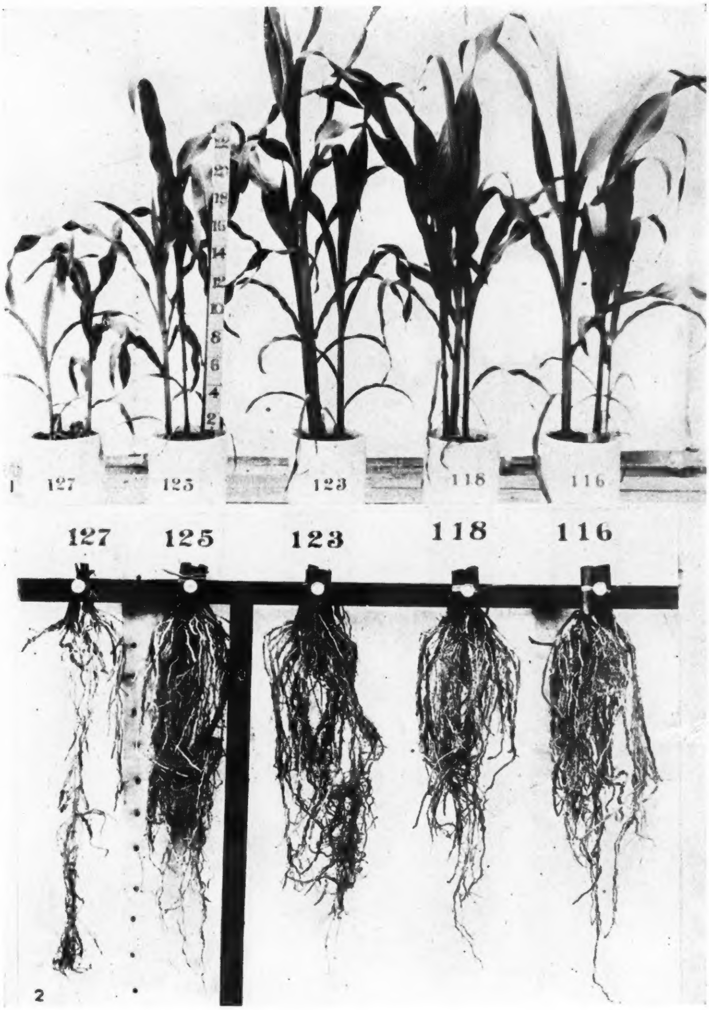
1
127
125
123
118
116
127
125
123
118
116
2

PLATE 9

FIG. 1. Bean plants photographed February 23. Borax at the rate of 10 pounds per acre was mixed with the upper 3 inches of soil in upper right-hand pot; in drills above the seed in upper left-hand pot; and in drills below the seed in lower left-hand pot. A commercial fertilizer containing about 1 per cent of borax was added at the rate of 500 pounds per acre to the lower right-hand pot.

FIG. 2. Bean plants photographed February 23. Borax, mixed with the upper 3 inches of soil, was applied at the rates of 20 pounds per acre in the first row at the bottom, 10 pounds per acre in the second, 5 pounds in the third and 2 pounds in the fourth row.

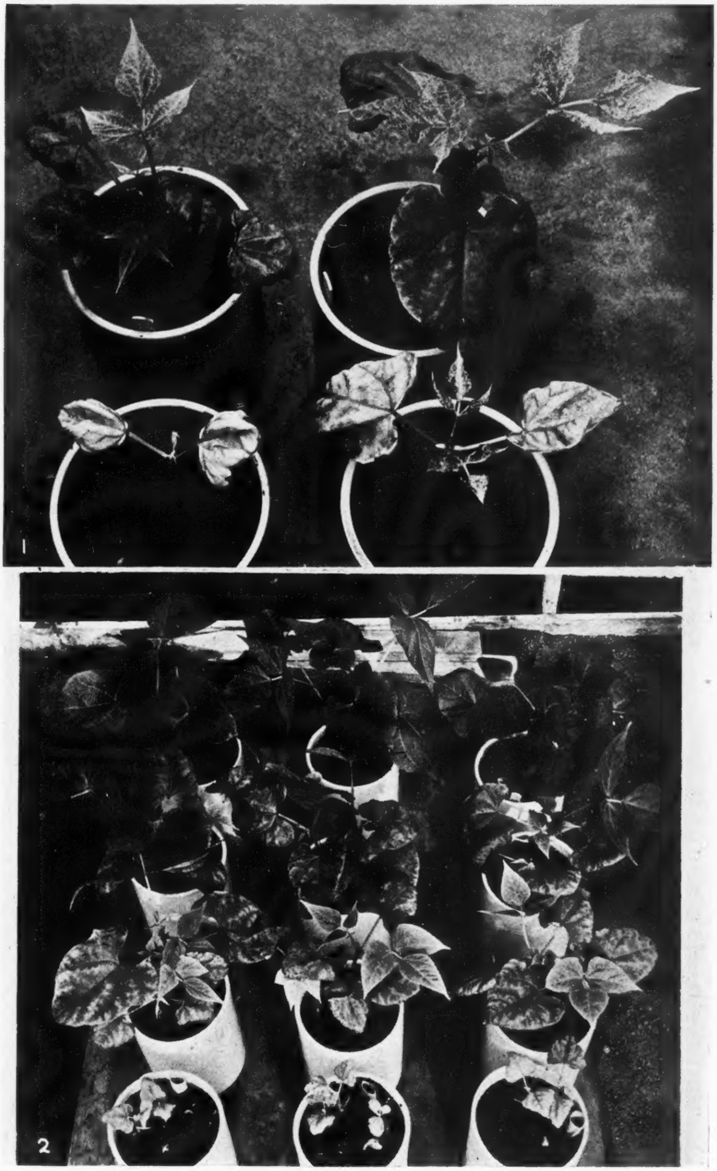
1
2

PLATE 10

Fig. 1. Bean plants photographed February 23. Borax applied at the rate of 10 pounds per acre as follows, beginning with the row (triplicate treatments) at the left; in the upper 3 inches of soil, in drills above, in drills below, in drills below with hydrated lime, and in drills below with the lime in the upper 3 inches.

Fig. 2. Bean plants photographed February 23. Borax applied at the rate of 5 pounds per acre in drills below together with additions as follows, beginning with the row at the left; gypsum mixed with the upper 3 inches, gypsum mixed with the borax-fertilizer mixture, borax-fertilizer only, hydrated lime mixed with the borax-fertilizer mixture, and hydrated lime mixed in the upper 3 inches.


10
LIME
1
GYPSUM
5
LIME
2

PLATE 11

FIG. 1. Bean plants photographed April 22. Series 7 received fertilizer in drills below together with borax at the rates of (left to right) 0, 2, 4, 6 and 8 pounds per acre. The pots in the row at the right received $4\frac{1}{2}$ pounds of borax per acre in a commercial fertilizer containing about 1 per cent of borax.

FIG. 2. Series 8 is the same as series 7 except that the soil was maintained at a moisture content of 15 per cent in series 8 and 30 per cent in series 7.

FIG. 3. Pot 31 received 10 pounds of borax per acre in drills above the seed, pot 51 the same amount mixed with the upper 3 inches of soil, and pot 10, 5 pounds per acre in drills below the seed. The pods as well as the leaves were bleached in pot 31.


1
SERIES 7
2
SERIES 8
3
31
51
10

PLATE 12

FIG. 1. Bean plants photographed April 12. Representative pots of the triplicate treatments of series 2 in which the fertilizer was in drills above the seed, together with the borax per acre as follows: none (pot 19), 1 pound (pot 22), 2 pounds (pot 27), 5 pounds (pot 28), 10 pounds (pot 33).

FIG. 2. Roots of the plants shown in figure 1, photographed April 12.

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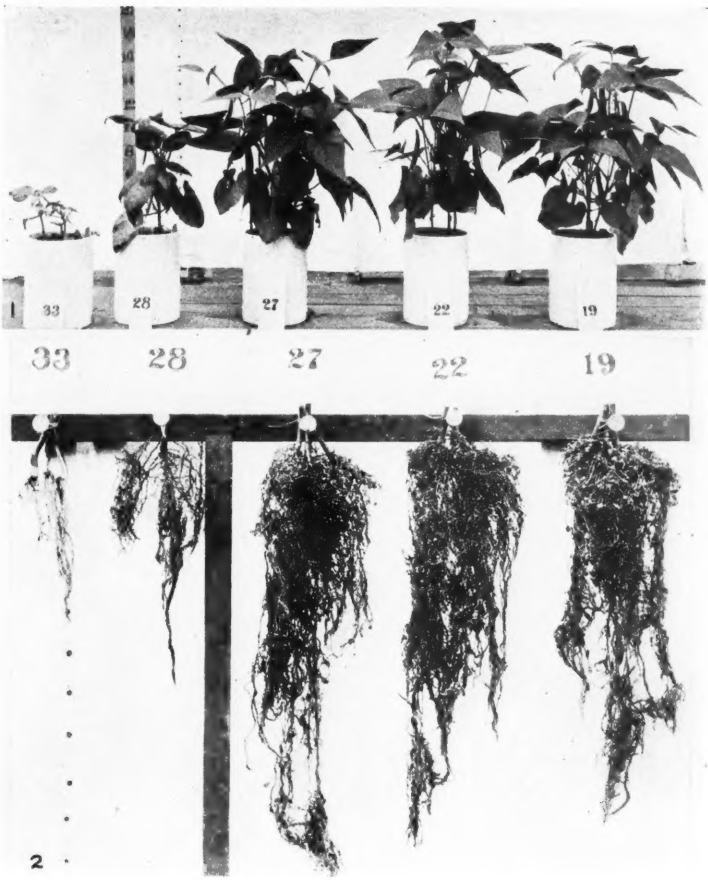
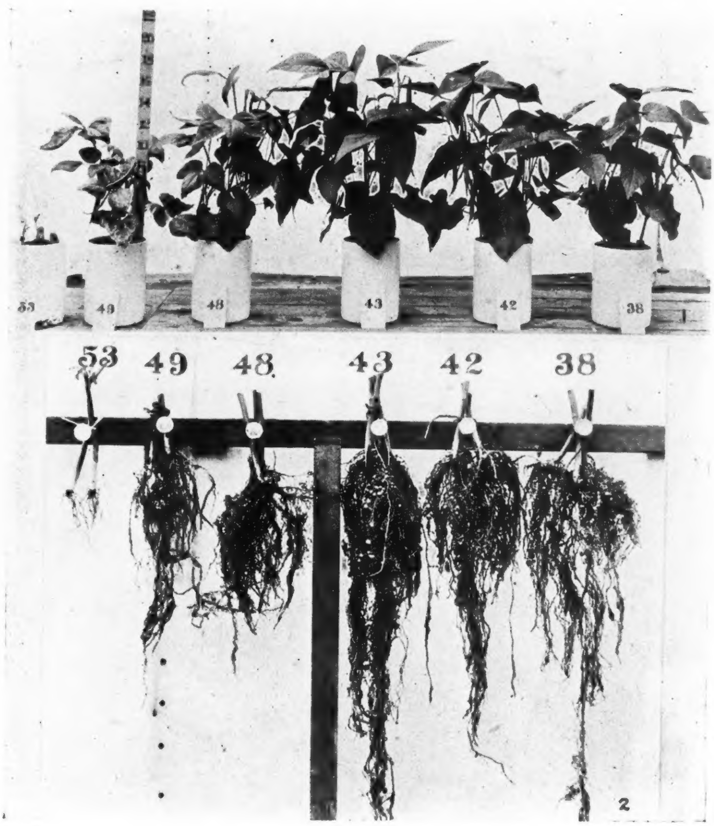


PLATE 13

FIG. 1. Bean plants photographed April 12. Representative pots of the triplicate treatments of series 3 in which the fertilizer was mixed with the upper 3 inches of soil together with borax at the following rates per acre: none (pot 38), 1 pound (pot 42), 2 pounds (pot 43), 5 pounds (pot 48), 10 pounds (pot 49), and 20 pounds (pot 53).

FIG. 2. Roots of the plants shown in figure 1, photographed April 12.


53
49
48
43
42
38
53
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48
43
42
38
2

SOIL ACIDITY AND BACTERIAL ACTIVITY[1]

R. E. STEPHENSON

Agricultural College, University of Kentucky

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INTRODUCTION

Just how and why soils become acid is a problem that has not yet been definitely solved. Neither is the effect of reaction upon the activity of soil organisms clearly understood. But is has been fairly well established that the process of nitrification once thought to be absent in acid soils, does proceed to an appreciable extent. In fact nitrification is perhaps sufficient for normal crop production, in most cases, provided the supply of organic matter is adequate. The process of ammonification which of course must precede nitrification is carried on by so many classes of organisms that it is not usually a limiting factor in crop production in either acid or sweet soils, under aerobic or anaerobic conditions.

In practically all soils there must be two analytical processes, the decomposition of organic matter, and the disintegration of minerals. The importance of microorganisms in bringing about these processes is too obvious to need comment. While these processes are occurring, plant growth also takes place. The general tendency of plant growth has been found to be to keep the nutrient solution nearly neutral. Crop production therefore doubtless has a tendency to prevent soils from becoming acid in reaction, while the leaching of bases has the opposite effect.

The cultivation of soils for crop production of course encourages leaching, stimulates bacterial activity, and on the whole in this indirect way must tend to produce acid soils.

In mineral disintegration, with the accompanying interchange of ions, both acids and bases must be set free. Similar effects are produced when organic matter is broken down. But changes in the organic portion of the soils must occur under favorable conditions much more rapidly than changes in the mineral portion. The acids and carbon dioxide produced in organic decay hasten mineral disintegration, and therefore increase the availability of mineral

[1] Part of the results of this study on "Soil Acidity and Bacterial Activity" has already been published. Two papers, "The Effect of Organic Matter on Soil Reactions. I," and "The Activity of Soil Acids" were published in Soil Science (6, 7), another paper "Nitrification in Acid Soils" is in press at the Iowa Agricultural Experiment Station. This paper is the first part of a thesis presented to the graduate faculty of the Iowa State College of Agriculture in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

plant-food. But though minerals are put into solution by these processes, there is also a compensating effect, in that organic decomposition products are capable of forming insoluble compounds with the minerals disintegrated and thus may prevent or at least retard the loss of the minerals by leaching.

One fact to be kept in mind in connection with both organic acids and with bases, is that so far as available data indicate, these compounds do not remain long as such. Oxidation changes convert the nitrogen bases to nitric acid and the organic acids to carbon dioxide. Only the nitric acid produced, therefore, is capable of causing a permanent direct effect upon soil reaction. Mineral bases and acids, on the other hand, are permanently removed from the soil primarily by leaching. The portion used by the plant may be expected to be returned to the soil, at least in part.

It may be observed, too, that practical experience demonstrates that soils containing sufficient organic matter remain more productive for a longer time than those soils which are low in organic matter. Loss of organic matter is likely to result in a sour, soggy, infertile soil, which does not respond to tillage or commercial fertilizer. Muck and peat soils are notable exceptions but largely because mineral elements, such as potassium and other bases, were never present. And again, such soils occur only under those conditions which favor a large production of organic acids, and prevent complete oxidation. These soils, therefore, are often highly acid, and this condition is undoubtedly due mainly to organic acids. But by way of contrast it must be observed that sandy soils and heavy clays, which do not contain sufficient organic matter to produce an appreciable acidity, are often highly acid and non-productive.

In this work one heavy silt loam soil, one soil somewhat sandy, both low in organic matter, and a loam soil rather high in organic matter were used, for the purpose of studying the changes which occur, the rate of change, and to some extent the final products of the reactions.

HISTORICAL

Previous investigations of the effect of organic matter upon the reaction of soils is very limited in amount and application. White (8), Skinner and Beatty (3), Miller (2) and Stephenson (6) found no positive evidence that the decay of organic matter in ordinary soils under conditions which would be favorable to crop production, produced any appreciable increase in the lime requirement of the soil. No argument is necessary, of course, to establish the fact that the large production of nitric acid would increase the acid reaction of the soil or use up bases rapidly if they were present.

THE PLAN OF THE EXPERIMENT

In a previous publication (6) the effect of the decomposition of albumin, casein, starch, blood, dextrose, alfalfa, and ammonium sulfate on the reaction of two soils was studied. Further work along this same line is reported here,

with organic materials of more general use such as farm manure, cottonseed meal, horse manure, timothy hay, clover hay, green timothy and green clover. Opportunity is thus afforded for comparing the green and the more matured dried materials.

Two of the same soils used in the earlier work were employed, one rather sandy and light in color, the other dark and fairly rich in organic matter, and of the loam type. Applications of the various materials were made at the rate of 10 tons per acre of air-dried material, on the basis of 2,000,000 pounds of soil per acre. The coarse materials were ground and thoroughly mixed with the soils, in 1-gallon earthenware jars. Samplings were made at intervals of 2, 5, 10, 15, and 22 weeks, respectively. Two series were run, one limed and the other unlimed. Determinations were made at each sampling for the ammonia, nitrates, acidity, and residual carbonates, since these are directly connected with the effect of materials on the soil reaction. A test was made at the second sampling, for the soluble non-protein nitrogen present in one of the soil types. This test should throw some light on the question of the possibility of any accumulation of soluble products of protein decomposition, other than nitrates and ammonia, and should also show whether there is any correlation between these products and the quantity of nitrates or ammonia present in soils.

AMMONIFICATION

The quantity of ammonia was determined by the aeration method, potassium carbonate being used to liberate the ammonia. Incidentally it may be said that experience at the Iowa Agricultural Experiment Station with this method would lead to the conclusion that those workers who have found the method unsatisfactory, must have experienced a faulty manipulation. The secret of successful operation of the method, is that the aeration must stir the soil completely to the bottom of the containing flask. The results of the ammonia determinations are given in table 1.

It may be observed that there is very little accumulation of ammonia with any of the treatments except the cottonseed meal. It has shown the greatest accumulation of ammonia at the first sampling and a greater accumulation when the soil was untreated, than when it was limed, both of which results agree with work done previously (6) with highly nitrogenous materials. There is too small an accumulation of ammonia on the untreated soils to show marked differences between the limed and the unlimed soils. The same may be said of most of the other treatments, though there is a greater amount of ammonia in the unlimed soils where green manures were added. The greatest amount of ammonia is found in nearly all cases at the first sampling before nitrification is well started. There is quite a marked difference in the two soils, noticeable where the cottonseed meal is used, in that the amount of ammonia throughout the test remains high on the unlimed sandy soil, while on the humus soil nitrification seems to have just about kept pace with

ammonification even in the absence of lime. This result lends support to the belief that soils containing sufficient organic matter are more active bacteriologically, and likewise usually more productive, than soils containing less organic matter even when the total time requirement is much greater for the organic soils.

The amount of ammonia produced may depend upon several factors. But when conditions are favorable for nitrification the ammonia is changed to nitrates almost as rapidly as produced.

TABLE 1

Amount of ammonia at the end of each period

TREATMENT	FIRST SAMPLE, 2 WEEKS		SECOND SAMPLE, 5 WEEKS		THIRD SAMPLE, 10 WEEKS		FOURTH SAMPLE, 15 WEEKS		FIFTH SAMPLE, 22 WEEKS		AVERAGES	
	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Humus soil:												
Soil alone.....	11.8	14.0	11.2	8.4	16.8	11.2	11.2	14.0	11.2	8.4	13.4	11.1
Cottonseed meal.......	302.4	285.6	268.8	61.6	98.0	22.4	86.8	19.6	32.0	14.0	157.6	80.6
Manure......	8.4	5.6	11.2	8.4	11.2	11.2	14.0	11.2	14.0	11.2	11.7	9.6
Timothy hay	5.6	8.4	11.2	11.2	16.8	11.2	11.2	5.6	11.2	11.2	11.2	9.5
Clover hay...	19.6	11.2	8.4	5.6	11.2	11.2	5.6	11.2	11.2	11.2	11.2	10.1
Green timothy.	44.8	11.2	14.0	5.6	16.8	11.2	11.2	11.2	11.2	11.2	19.6	10.1
Green clover..	33.6	14.0	16.8	5.6	16.8	11.2	11.2	8.4	11.2	8.4	17.9	9.5
Average....	61.6	50.0	48.8	15.2	22.8	12.8	21.6	11.6	14.6	10.8	48.5	28.1
Sandy soil:												
Soil alone.....	56.0	30.8	14.0	5.6	16.8	11.2	19.6	11.2	14.0	14.0	24.1	14.6
Cottonseed meal.......	294.8	305.2	280.0	100.8	132.5	16.8	151.2	22.4	14.0	19.6	194.5	92.9
Manure......	16.8	19.6	8.4	11.2	8.4	11.2	8.4	8.4	11.2	11.2	10.6	12.3
Timothy hay..	11.2	8.4	11.2	8.4	16.8	11.2	14.0	11.2	11.2	89.6	12.9	25.8
Clover hay...	39.2	39.2	19.6	11.2	14.0	14.0	11.2	8.4	16.8	14.0	20.1	17.4
Green timothy.	58.8	47.6	33.6	16.8	14.0	8.4	11.2	8.4	5.6	5.6	24.6	17.8
Green clover..	103.6	75.6	39.8	14.0	11.2	11.2	11.2	11.2	5.6	5.6	32.5	23.5
Average....	97.2	75.2	56.8	24.0	30.5	12.0	32.4	11.6	17.2	22.8	45.6	29.2

Lime favors nitrification and at least in that indirect way indicates a retarded ammonification. Lime also increases the number of organisms, and should therefore tend to reduce the total of ammonia and nitrates in the presence of a limited supply of organic matter, because of greater nutritional demands by the increased number of organisms. When a large amount of nitrogenous organic matter is added perhaps this would not result. And since the ammonification process is the actual limiting factor under conditions which permit of nitrification, the increased basicity due to the use of lime evidently does have a retarding effect.

When averages are taken of all determinations and all treatments, there is no case on the humus soil (so-called because of its higher content of organic matter) where lime has not diminished the amount of ammonia produced. On the sandy soil there are two cases, with manure and with timothy hay, where the reverse is true, but the result would appear to be more nearly accidental than fundamental.

TABLE 2

Nitrates at each successive sampling

TREATMENT	FIRST SAMPLE, 2 WEEKS		SECOND SAMPLE, 5 WEEKS		THIRD SAMPLE, 10 WEEKS		FOURTH SAMPLE, 15 WEEKS		FIFTH SAMPLE, 22 WEEKS		AVERAGE	
	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Humus soil												
Soil alone.....	28.6	19.1	63.5	68.8	38.9	95.9	52.3	102.0	50.0	121.1	64.7	83.4
Cottonseed meal.......	33.0	45.7	98.3	243.2	214.8	309.0	302.4	289.9	324.0	316.0	194.5	240.8
Manure......	14.2	7.3	21.4	23.8	37.8	57.8	36.7	61.8	74.5	104.1	36.9	50.9
Timothy hay.	Tr.*	Tr.	Tr.	Tr.	Tr.	20.5	Tr.	35.5	22.8	67.4	4.5	24.7
Clover hay...	40.6	58.9	67.8	92.5	80.3	129.5	86.3	133.5	116.7	170.8	78.3	117.0
Green timothy.	45.6	51.5	100.4	83.9	180.5	125.0	141.1	93.8	181.4	121.4	129.8	94.9
Green clover..	69.4	78.1	109.7	122.0	234.1	319.1	181.5	168.1	284.6	201.0	175.8	177.6
Average....	33.1	37.2	65.9	90.6	112.3	150.9	114.3	127.8	150.6	165.9	95.2	112.8
Sandy soil:												
Soil alone.....	17.7	16.6	58.6	72.4	85.0	58.8	97.6	73.1	81.6	103.8	68.1	65.9
Cottonseed meal.......	9.4	7.3	112.2	138.3	167.9	229.4	267.6	400.2	312.4	457.4	173.9	246.5
Manure......	11.2	19.1	38.2	52.1	53.1	62.1	61.4	68.8	61.8	89.8	45.0	54.4
Timothy hay..	Tr.	Tr.	Tr.	Tr.	Tr.	14.8	Tr.	41.5	21.3	50.3	4.2	21.3
Clover hay...	11.5	15.1	63.6	97.1	83.5	69.5	90.7	122.0	123.1	152.4	74.5	91.2
Green timothy.	12.1	23.3	66.1	86.6	100.7	82.4	92.0	88.0	105.3	144.3	75.2	84.9
Green clover..	16.4	13.7	86.0	109.3	153.3	117.9	147.3	135.5	207.4	183.7	122.1	112.0
Average....	11.2	13.6	60.7	79.4	90.0	90.7	108.0	129.9	130.3	168.8	80.4	96.6

* Tr. = trace.

NITRIFICATION

For the determination of nitrates the phenoldisulfonic acid method as modified by Davis (1) was used. Calcium carbonate was employed to flocculate the soil and secure a clear filtrate. The results are given in table 2.

It is observed that the amount of nitrates increased in the untreated soils up to the last sampling.

The cottonseed meal, in accordance with its higher nitrogen content, gave a greater accumulation of nitrates on both soils than any other treatment. Here again, the sandy soil, though starting more slowly, finally ran higher than the better soil. On both soils, the greatest amount of nitrate was found at

the last sampling, the first two samples on the sandy soil showing less than the untreated soil. In most cases lime increased the nitrification of cottonseed meal.

The addition of stable manure caused a decrease in the amount of nitrates present in most cases, probably because of an increased number of organisms greater than the accompanying addition of easily nitrifiable material.

Timothy hay had the same effect as stable manure but to a much more marked degree. Little nitrifiable material was added in the timothy, but considerable energy material was provided, and the organisms used most of the nitrates for nutritional purposes. The nitrates began to show at about the same time on both soils but never ran nearly so high as on the untreated soils. Lime again stimulated nitrification. The green timothy in contrast to the dry, stimulated nitrification at once on both soils, and the greatest accumulation of nitrates was found at the last sampling and in the presence of lime.

Dry clover also caused a gradual stimulation of nitrification, the greatest effect being produced at the last sampling. The stimulation was usually greater also in the presence of lime. The green clover had a somewhat greater effect than did the dry, and maximum nitrification was induced sooner.

When averages of all samplings and all treatments are taken, the humus soil shows greater nitrification in the presence of lime in every case except one, and this is where green timothy was applied. There is very little difference with the green clover. When the sandy soil is considered the soil alone produces slightly less nitrates on the limed series. Every treatment except one, and in this case it is green clover, has shown greater nitrification in the presence of lime. Apparently the lime does not affect the nitrification of the green material as much as some of the dried materials. As is quite logical, the greatest amount of nitrates is found at the last sampling, while the greatest amount of ammonia is usually found at the first sampling.

A summary of the nitrate and ammonia determinations is given in table 3. The table shows the largest combined production of nitrates and ammonia where cottonseed meal was applied, followed in order by green clover, green timothy, horse manure, and dry timothy, the latter two producing considerably less than the soil alone. The general effect of the lime was to decrease the total of nitrates and ammonia found, especially where there was any large production.

ACIDITY RESULTS

The lime requirements on the soils differently treated are given in table 4. The determinations were made according to the modified Tacke method previously described (5). The acid soil was brought into contact with pure calcium carbonate, and the aeration and shaking continued for 10 hours before titrations were made. The double-titration was performed, with methyl-orange and phenolphthalein as indicators.

TABLE 3

Nitrogen summary; summary of ammonia and nitrates

TREATMENT	FIRST SAMPLE 2 WEEKS		SECOND SAMPLE 5 WEEKS		THIRD SAMPLE 10 WEEKS		FOURTH SAMPLE 15 WEEKS		FIFTH SAMPLE 22 WEEKS		AVERAGE			
	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime		Lime	
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	Minus soil *p.p.m.*	*p.p.m.*	Minus soil *p.p.m.*
Humus soil:														
Soil alone	45.5	33.1	74.7	77.3	55.7	107.2	63.6	131.1	61.2	134.5	60.1		96.6	
Cottonseed meal	335.5	331.3	367.1	304.8	312.9	331.4	338.2	309.5	346.1	330.0	339.9	279.8	321.4	224.8
Manure	22.6	13.0	32.6	33.3	49.3	69.0	50.8	73.0	88.5	115.3	48.7	−11.4*	60.7	−35.9*
Timothy hay	5.6	8.4	11.2	11.2	16.8	31.6	11.2	41.1	34.0	78.6	15.7	−44.4*	34.2	−62.4*
Clover hay	79.2	70.1	76.5	98.1	91.5	140.6	91.9	144.7	127.7	170.8	93.4	33.3	124.8	28.2
Green timothy	90.4	62.7	114.4	89.5	197.3	136.1	152.2	105.0	192.6	132.6	149.4	89.3	105.2	8.6
Green clover	103.1	92.1	125.5	127.6	250.9	330.3	192.7	176.5	295.8	209.4	193.8	133.7	187.2	90.6
Average											128.7	134.0	132.9	88.1
Sandy soil:														
Soil alone	73.8	37.4	72.6	78.0	101.8	70.0	117.2	84.8	95.6	117.8	92.2		77.6	
Cottonseed meal	404.2	312.5	392.2	239.1	300.4	246.2	418.8	422.6	326.4	477.0	368.4	276.2	339.5	261.9
Manure	28.0	38.7	46.6	63.4	61.5	73.7	69.5	57.2	72.6	101.0	55.6	−36.6*	66.8	−10.8*
Timothy hay	11.2	8.4	11.2	8.4	16.8	26.1	14.0	52.7	32.5	139.9	17.1	−75.1*	47.1	−3.0*
Clover hay	50.8	54.3	143.2	107.3	97.6	83.5	101.9	130.4	139.8	171.4	106.7	14.5	109.4	31.8
Green timothy	70.9	70.9	99.7	103.4	114.7	90.8	103.2	101.4	110.9	149.9	99.9	7.7	103.3	25.7
Green clover	114.0	89.3	116.8	123.3	164.5	129.1	158.5	146.7	212.6	189.3	153.3	61.1	135.5	57.9
Average											127.6	89.9	125.6	94.3

* These are omitted in taking final averages.

There is little to be said in regard to the effect of the various treatments upon the lime requirement of the soils. The general tendency has been to reduce rather than to increase it. A large production of ammonia reduces the lime requirement, and, quite logically, when nitrification occurred the opposite effect resulted.

TABLE 4

Lime requirement of the variously treated soils in tons per 2,000,000 pounds soil

TREATMENT	FIRST SAMPLE, 2 WEEKS	SECOND SAMPLE, 5 WEEKS	THIRD SAMPLE, 10 WEEKS	FOURTH SAMPLE, 15 WEEKS	FIFTH SAMPLE, 22 WEEKS	MORE OR LESS THAN THE SOIL ALONE				
						First sample	Second sample	Third sample	Fourth sample	Fifth sample
	tons	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*
Humus soil:										
Soil alone	3.90	4.20	3.85	3.80	3.80					
Cottonseed meal	3.65	3.65	4.45	4.25	4.55	−0.25	−0.55	+0.60	+0.45	+0.75
Manure	3.80	4.25	3.60	3.40	3.80	−0.10	+0.05	−0.25	−0.40	+0.00
Mature timothy	4.05	4.15	3.55	3.35	3.55	+0.15	+0.05	−0.30	−0.45	−0.25
Mature clover	3.35	4.15	3.65	3.25	3.95	−0.05	−0.05	−0.20	−0.55	+0.15
Green timothy	4.10	4.45	3.70	3.65	3.95	+0.20	+0.25	−0.15	−0.15	+0.15
Green clover	3.6	4.00	3.25	3.20	3.85	−0.20	−0.20	−0.60	−0.60	+0.05
Sandy soil:										
Soil alone	3.20	2.60	2.35	2.40	2.35					
Cottonseed meal	1.70	2.15	2.15	2.50	2.45	−0.50	−0.45	−0.20	+0.10	+0.10
Manure	2.20	2.35	2.10	2.65	1.75	0.00	−0.25	−0.25	+0.25	−0.60
Mature timothy	2.20	2.30	1.80	2.05	1.75	0.00	−0.30	−0.55	−0.35	−0.60
Mature clover	2.15	2.30	1.90	1.80	1.75	−0.05	−0.30	−0.45	−0.60	−0.60
Green timothy	2.55	2.65	2.25	2.30	2.00	+0.35	+0.05	−0.10	−0.10	−0.35
Green clover	1.70	2.65	1.90	1.90	1.85	−0.50	+0.05	−0.45	−0.50	−0.50

TABLE 5

Difference of ammonia and nitrates on unlimed soils compared with effect of treatment on lime requirement

Humus soil:					
Ammonia (p.p.m.)	302.4	268.8	98.0	86.8	32.0
Nitrates (p.p.m.)	33.0	98.3	214.8	302.4	324.0
Difference (p.p.m.)	+269.4	+170.5	−116.8	−215.6	−292.0
Difference in lime requirement (tons)	−0.25	−0.55	+0.60	+0.45	+0.75
Sandy soil:					
Ammonia (p.p.m.)	394.8	280.0	132.5	151.2	14.0
Nitrates (p.p.m.)	9.4	112.2	167.9	267.6	312.4
Difference (p.p.m.)	+385.4	+168.8	−35.4	−116.4	−298.4
Difference in lime requirement (tons)	−0.50	−45.0	−0.20	+0.10	+0.10

Table 5 brings out this point when the cottonseed meal treatment is studied, in comparing the effect of ammonification and nitrification upon the decrease or increase of the lime requirement of the treated soil over the untreated.

This table shows that though there is not a close correlation between the difference of ammonia and nitric acid produced on the soils treated with cottonseed meal, and the effect upon the lime requirement, the tendency is for the soil to show a greater or smaller lime requirement according as there is more or less of the nitrogen present in the basic or acid form. None of the other treatments contain sufficient nitrogen to make the comparison significant.

TABLE 6

Residual carbonates on treated soils; expressed in tons per acre

TREATMENT	FIRST SAMPLE, 2 WEEKS	SECOND SAMPLE, 5 WEEKS	THIRD SAMPLE, 10 WEEKS	FOURTH SAMPLE, 15 WEEKS	FIFTH SAMPLE, 22 WEEKS	MORE OR LESS THAN SOIL UNTREATED				
						First sample	Second sample	Third sample	Fourth sample	Fifth sample
	tons	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*
Humus soil:										
Soil alone	3.40	2.55	2.00	1.95	1.35					
Cottonseed meal	4.95	2.55	1.20	1.25	0.55	+1.55	+0.00	−0.80	−0.70	−0.80
Manure	4.10	2.85	2.45	1.90	2.05	+0.70	+0.30	+0.45	−0.05	+0.70
Dry timothy	4.35	2.90	2.35	2.10	1.90	+0.95	+0.35	+0.35	+0.15	+0.55
Dry clover	4.15	3.05	2.30	2.10	2.15	+0.75	+0.50	+0.30	+0.15	+0.80
Green timothy	4.05	3.20	2.50	2.30	2.15	+0.65	+0.65	+0.50	+0.35	+0.80
Green clover	4.20	3.00	2.95	2.50	2.45	+0.80	+0.45	+0.95	+0.55	+1.10
Sandy soil:										
Soil alone	2.80	2.55	2.45	2.55	2.40					
Cottonseed meal	3.90	2.35	1.70	1.20	0.85	+1.10	−0.20	−0.75	−1.35	−1.55
Manure	2.95	2.70	2.65	2.60	2.40	+0.15	+0.15	+0.20	+0.05	+0.00
Dry timothy	3.25	2.75	2.45	2.60	2.35	+0.45	+0.20	+0.00	+0.05	−0.05
Dry clover	3.30	3.00	2.75	2.90	2.50	+0.50	+0.45	+0.30	+0.35	+0.10
Green timothy	2.80	2.55	2.50	2.40	2.30	+0.00	+0.00	+0.05	−0.15	−0.10
Green clover	4.25	3.30	3.00	3.00	2.85	+0.45	+0.75	+0.55	+0.45	+0.45

RESIDUAL CARBONATES

The residual carbonates were determined by decomposing the remaining limestone with dilute acid, and titrating the carbon dioxide liberated, in the same way as the titration was made in the lime-requirement determinations. The results are given in table 6.

Lime was applied at the rate of 7 tons on the more acid soil and 6 tons on the other soil, in the form of the precipitated carbonate. As was intended a sufficient excess was added so that nitrification did not exhaust it.

The data show that in most cases the organic materials have tended to protect the lime applied to the soil. The notable exception is the cottonseed meal, which on account of the large production of nitric acid, has used up the

carbonates nearly completely. All of the treatments helped to save limestone until nitrification occurred, as noted by the fact that with but three exceptions minus quantities do not appear until the last two samplings.

SOLUBLE NON-PROTEIN NITROGEN

The method employed in this study was in general that used by Potter and Snyder (4). The soil was extracted with 1 per cent hydrochloric acid, in both the limed and the unlimed series. The nitrate nitrogen and the ammonia nitrogen were distilled off by the Devarda reduction method. The residue from this reduction was then treated with sulfuric acid and the total nitrogen determined in the usual way. This latter gave the unknown soluble non-protein nitrogen of the acid extract.

The acid-extracted soil was next extracted by shaking 2 hours with 1.75 per cent sodium hydroxide, and the extract clarified by centrifuging for 5 minutes at 30,000 revolutions per minute. The extract was then neutralized with sulfuric acid, and acidified with tri-chlor-acetic acid sufficiently to give 2½ per cent of the latter. The precipitate was then filtered off and another aliquot of the filtrate taken for determination of the nitrogen by the micro-method.

TABLE 7

Soluble non-protein nitrogen in humus soil after 5 weeks

TREATMENT	UNKNOWN NON-PROTEIN NITROGEN				TOTAL UNKNOWN NON-PROTEIN NITROGEN	
	In HCl extract		In alkaline extract			
	No lime	Lime	No lime	Lime	No lime	Lime
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Soil alone	23.33	26.00	245.5	246.5	268.83	272.50
Cottonseed meal	195.99	44.66	310.5	287.5	506.49	355.16
Manure	32.66	11.33	246.5	218.0	278.16	229.33
Timothy	28.66	29.99	232.0	253.0	260.66	282.99
Clover	23.33	26.00	260.5	244.0	283.83	270.00
Green timothy	35.33	30.00	266.0	253.0	301.33	283.00
Green clover	28.66	19.60	277.3	253.3	305.96	272.90

Soluble non-protein materials should probably be the largest in amount when decomposition is the most active. But the question is, do these compounds, many of which are doubtless of a peptide character, tend to accumulate in soils in appreciable amounts, or do ammonification and nitrification proceed at once when the decomposition has started. In other words, should the soluble nitrogen be found primarily in the form of ammonia and nitrates or also in more complex forms? Previous study has shown that plants are capable of using more complex forms of nitrogen than nitrates and ammonia, and if they occur to any extent in ordinary soils, there may be conditions when such complex compounds function as direct sources of plant-food.

The results show in every case but one (timothy) that the application of lime has diminished the total unknown soluble non-protein nitrogen. The nitrates and ammonia, though soluble non-protein nitrogen, are not included in these data. A reference to table 3 shows that this is the same general tendency as observed in the production of ammonia. There is one noticeable fact, and that is that none of the organic treatments have as marked an effect upon the amount of unknown soluble non-protein nitrogen as they have on the nitrates and ammonia. This indicates, as do also the data of Potter and Snyder (4), that in the decomposition of proteins of the soil the degradation products undergo rather rapidly a complete change to the simpler state of ammonia. and nitrate. Except in case of the more resistant forms, possibly polypeptides of some degree of complexity, the products apparently do not accumulate to a large extent, and the nitrogen of the soil must exist mostly as the more complex and resistant forms or else as the simplest possible products of decomposition. Ordinarily, of course, nitrates and ammonia are removed from the soil almost as rapidly as produced, and therefore they are not found in large amounts at any one time. Hence the soluble non-proteins such as are found in this study are probably present at any definite time in perhaps five or even ten times the amount of ammonia and nitrates present.

Another question to consider is the possible effect of such compounds on the reaction of the soil. Though perhaps capable of reaction as either acids or bases, they are not found in sufficient quantity to exert a marked effect upon soil reaction. Such materials and others, however, doubtless exercise a buffering effect and help to reduce the hydrogen-ion concentration to some extent.

GENERAL DISCUSSION

This experiment was continued for 159 days, or about 22 weeks. It is not presumed that there would be no change after this time, but rather that such changes as occurred previous to this would determine whatever effects were to be produced by the different treatments on the activity of soil organisms or the reaction of the soil.

The materials used contained the following percentages of nitrogen: dry timothy, 0.693; manure, 1.24; green timothy, 1.28; dry clover, 2.30; green clover, 2.82; and cottonseed meal, 6.96 per cent. The poorer soil contained 0.116, and the better soil about twice as much, or 0.238 per cent, of nitrogen. The amounts of nitrogen found as ammonia and nitrates were for the most part in the same order as the percentages of nitrogen contained in the materials used.

No definite conclusions may be drawn from a limited study, but in general it seems that the essential soil organisms are active in soils of at least moderately strong acidity. The data indicate also that the decay of organic materials under aerobic conditions does not produce an appreciable acidity except where nitric acid is formed in nitrification.

SUMMARY

1. The lime requirement of neither soil was increased by the organic treatments except in those cases where there was a large production of nitric acid.

2. Ammonification is apparently greater in the absence of lime, partly perhaps because of the fact that nitrifying organisms have been less active.

3. Lime has generally stimulated nitrification.

4. The sum of ammonia and nitrates is usually greater on the unlimed soil when treated with nitrogenous organic materials. This is doubtless partly due to the increased number of organisms in the presence of lime and the consequent greater consumption of nitrates and ammonia by the organisms.

5. When nitrogenous sources of energy such as horse manure and timothy hay were supplied, nitrifiction and ammonifiction were reduced below that of the untreated soil.

6. The green materials were somewhat more readily attacked than the dried materials. There was greater production of ammonia and nitrates partly however because of the fact that these materials were richer in nitrogen than the mature plants.

7. The soluble unknown non-protein nitrogen determined at the second sampling on the more fertile soil, when the activity of the organisms was nearly at the maximum, showed little effect due to the various organic treatments. The cottonseed meal was the only treatment which gave any large increase over the untreated soil.

8. In all cases but one, the unlimed treatments gave a higher non-protein nitrogen content than the limed.

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THE EFFECT OF ORGANIC MATTER ON SOIL REACTION. II[1]

R. E. STEPHENSON

Agricultural College, University of Kentucky

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INTRODUCTION

A study on the effect of organic matter on soil reaction was undertaken as a part of an extended investigation of soil acidity. For a description of the background of the experiments here reported, experimental methods, etc., the reader is referred to the preceding study (5), also to a former study of the same problem (4).

In this series of treatments the organic materials were applied at the same rates as before (10 tons) (4) except where dried blood and straw were mixed and then blood was used at the rate of 10 tons, with 5 and 10 tons of straw. Precipitated carbonate of lime was added to the limed treatments at the uniform rate of 5 tons per acre. The materials used were soybean hay, green rape, oat straw, green soybean hay (pods removed), dried blood and a mixture of blood and oat straw, all in both the limed and the unlimed series. The green materials were dried, as were also the other materials, and ground as finely as was convenient before adding to the soil. The soil used in this study was an acid silt loam taken from the West Virginia Agricultural Experiment Station farm, rather heavy and compact, and poor in organic matter.

The total period of incubation was 125 days, samplings being made at intervals of 2, 5, 10 and 18 weeks, respectively. In addition to the determinations made in the study of the previous series, hydrogen-ion determinations were made upon all treatments.

AMMONIFICATION

The aeration method was again used for ammonia. The results are shown in table 1, expressed as parts of nitrogen per million of soil.

Only the blood possessed a high nitrogen content and therefore it is the only material which caused a large production of ammonia.

[1] This paper is the second part of a thesis presented to the graduate faculty of the Iowa State College of Agriculture in partial fulfillment of the requirements for the degree of Doctor of Philosophy. It is also the second paper published on this study, the former (4) having appeared in 1919. A portion of the work here reported was completed at the Iowa Agricultural Experiment Station, and the remainder was conducted in consultation with Prof. R. M. Salter at West Virginia University. Acknowledgments are extended to Dr. P. E. Brown, of Iowa State College, and also to Professor Salter, for helpful suggestions in planning and interpreting the work.

Lime produced no marked effect in the ammonification of any of the materials until the third sampling, when it caused an appreciable reduction, which was still very evident at the last sampling. This may have been due to two causes. The lime may have caused greater numbers of organisms to grow, which in turn caused a greater consumption of ammonia. The principal cause, no doubt, was that lime permitted greater nitrification, and most of the ammonia had been changed over to nitrate. The data show that this had occurred.

The oat straw depressed ammonification just as it did nitrification, in most cases below that of the untreated soil; this would indicate that it was a suitable source of energy for bacterial activity.

Green soybeans likewise depressed ammonification below that of the soybean hay but partly because of the fact that their nitrogen content was lower.

TABLE 1

Amount of ammonia at the end of each period

TREATMENT	FIRST SAMPLE, 2 WEEKS		SECOND SAMPLE, 5 WEEKS		THIRD SAMPLE, 10 WEEKS		FOURTH SAMPLE, 18 WEEKS		AVERAGES	
	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Silt loam soil:										
Soil alone	3.6	50.0	32.0	34.0	60.0	5.6	16.0	12.0	36.0	2.54
Soybean hay	94.0	106.0	107.0	106.0	92.4	8.7	36.0	8.0	82.4	57.2
Green rape	182.0	168.0	178.0	132.0	36.4	8.7	64.0	4.0	115.1	78.2
Green soybeans	48.0	63.0	40.0	56.0	16.9	22.2	12.0	8.0	29.2	38.5
Oat straw	52.0	20.0	24.0	16.0	13.8	5.6	10.4	8.0	25.1	12.4
Blood	342.0	282.0	566.0	425.0	546.0	361.2	328.0	54.0	445.5	287.3
Blood and 5 tons of straw	242.0	316.0	424.0	400.0	336.2	43.2	440.0	48.0	360.5	201.8
Blood and 10 tons of straw	226.0	300.0	396.0	306.0	288.4	26.8	366.0	32.0	319.1	166.2
Averages	169.4	180.0	247.9	209.7	190.1	68.1	179.5	23.1	196.7	120.2

Green rape, on the other hand, stimulated ammonification next to the dried blood. However, it contained a little less nitrogen than the soybean hay, though more than the green soybeans.

Straw mixed with blood had little consistent effect upon ammonification. However, the ammonia produced by the combined application of blood and straw was seldom greater and often less than that produced from the blood alone.

There were individual cases where the limed treatments produced more ammonia than the unlimed, but when averages of all treatments (omitting the soil alone) and of all samples, were taken, the unlimed treatments have produced a greater quantity of ammonia. The difference is quite marked at later samplings when nitrification is well under way.

The data show that the accumulation of nitrates has increased at each successive sampling with all treatments, as well as with the untreated soil,

in both the limed and the unlimed series. In general, there has been greater nitrification in the presence of lime. This is more noticeable after the first sampling and with the nitrogen rich materials. Lime apparently had the opposite effect where oat straw was used. Straw used with blood retarded nitrification at first but later there was little or no retardation. The maximum amount of nitrates occurred at the last sampling in most cases.

Apparently the green soybeans began to nitrify more quickly than did the soybean hay. Green rape likewise at once stimulated nitrification to an appreciable extent.

NITRIFICATION

Nitrates were determined by the colorimetric method as before. The results are shown in table 2.

TABLE 2

Nitrates at each successive sampling

TREATMENT	FIRST SAMPLE, 2 WEEKS		SECOND SAMPLE, 5 WEEKS		THIRD SAMPLE, 10 WEEKS		FOURTH SAMPLE, 18 WEEKS		AVERAGES	
	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Silt loam soil:										
Soil alone	19.6	23.0	24.8	33.3	38.4	54.6	65.3	113.8	37.0	56.2
Soybean hay	25.9	25.7	28.8	37.9	71.8	181.1	122.6	195.3	62.3	110.0
Green rape	76.1	96.6	79.0	75.1	120.5	234.1	260.3	188.7	133.9	148.6
Green soybeans	42.5	27.2	388.5	39.7	83.5	108.2	175.7	109.0	172.5	71.0
Oat straw	19.8	Tr.*	19.6	4.6	26.3	16.2	38.6	38.9	26.1	15.4
Dried blood	14.2	9.1	24.5	40.7	149.1	485.5	353.3	611.1	135.3	286.6
Blood and 5 tons of straw	8.6	Tr.	17.3	37.1	160.3	280.9	332.7	640.0	129.8	264.5
Blood and 10 tons of straw	Tr.	Tr.	59.1	59.8	156.9	492.5	413.0	575.4	157.2	281.9
Average	26.7	22.7	88.2	42.1	109.8	271.5	242.3	336.9	116.7	168.3

* Tr. = trace.

Nitrification apparently scarcely occurred in the presence of oat straw until the third and fourth samplings. In no case was there as much nitrate as on the untreated soil.

Nitrification was slow in starting when blood and straw were mixed but by the end of 10 weeks there was an appreciable accumulation of nitrates on the treated soils over the untreated. Apparently the addition of straw had no marked effect upon the nitrification of dried blood.

When averages of all treatments and all samplings are taken (omitting the untreated soil) it is observed that nitrification was slow in starting where straw and blood and mixtures of the two were used, but the blood-straw mixtures finally ran high. Lime in these cases seems to have retarded the beginning of the nitrifying process, but perhaps more organisms were present where lime was added and they were consuming such nitrates as were produced.

The nitrogen summary shown in table 3 indicates that the average total of nitrates and ammonia has been greatest in most cases for the treated soils, when not limed, but that the reverse is true for the untreated soil. Whether the difference may be due to numbers of organisms and the consequent utilization of part of the nitrogen changed on treated limed soils, cannot be stated, though it seems probable. Experience has shown that in nearly every case a carbohydrate material such as straw which is poor in nitrogen, has given a decrease in ammonia and nitrates over the soil alone, either limed or unlimed. Since the ammonia and nitrate forms of nitrogen are by-products of the attempt of the organism to secure sufficient energy, this is to be expected.

TABLE 3

Nitrogen summary, nitrates and ammonia

TREATMENT	FIRST SAMPLE, 2 WEEKS		SECOND SAMPLE, 5 WEEKS		THIRD SAMPLE, 10 WEEKS		FOURTH SAMPLE, 18 WEEKS		AVERAGE			
	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime		Lime	
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	Minus soil	*p.p.m.*	Minus soil
Silt loam soil:												
Soil alone	55.6	73.0	57.3	67.3	98.4	59.9	81.3	125.8	73.1	*p.p.m.*	81.5	*p.p.m.*
Soybean hay	120.0	131.8	130.8	144.0	164.2	189.8	158.6	203.3	143.4	70.3	167.2	85.7
Green rape	258.1	264.6	257.0	207.1	156.9	242.8	324.3	192.7	249.1	176.0	226.8	145.3
Green soybeans	90.5	95.2	78.5	95.7	100.4	130.4	187.7	117.0	114.3	−41.2	109.8	28.3
Oat straw	71.8	20.0	43.6	20.6	40.1	23.8	49.1	46.9	51.2	−21.9	27.8	−53.7
Dried blood	356.2	291.1	590.6	492.7	745.1	846.7	681.1	665.1	580.8	507.7	548.9	467.4
Blood and 5 tons of straw	250.6	316.0	441.8	437.3	496.5	424.1	777.7	687.9	491.7	418.6	475.8	394.3
Blood and 10 tons of straw	266.0	300.0	455.0	365.8	445.3	519.2	779.0	607.4	477.2	404.1	488.1	366.6
Average	196.1	202.7	336.1	251.8	299.9	339.6	421.8	360.0	301.1		286.3	

LIME REQUIREMENT

The data show that in nearly every case the lime requirement was less when organic matter was added to the soil (table 4). The greatest effect was usually at the first sampling. This was especially marked with the dried blood which produced large amounts of ammonia. Next to blood, soybean hay produced the greatest effect; green rape was next and oat straw last. Thus it seems that nitrogenous materials, by their production of ammonia and perhaps by other reactions, reduce the lime requirement of soils. The effect has been more marked and consistent on this rather heavy soil than on the lighter soils previously studied. Carbohydrate materials have much smaller effects.

It is shown also that the limed soils have a capacity for decomposing limestone, even after 18 weeks' standing with an excess of lime. This would indicate that acid soils react with carbonate of lime beyond the neutral point, or that for lack of sufficiently intimate contact, all the acids have not yet been neutralized. There is perhaps no such thing as completion of the reaction. There are doubtless always soluble acids or acid salts capable of decomposing the carbonate.

TABLE 4

Lime requirement of variously treated soils (tons per 2,000,000 pounds)

	FIRST SAMPLE, 2 WEEKS	SECOND SAMPLE, 5 WEEKS	THIRD SAMPLE, 10 WEEKS	FOURTH SAMPLE, 18 WEEKS	MORE OR LESS THAN SOIL ALONE			
					First sample	Second sample	Third sample	Fourth sample
	tons	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*
Clay soil:								
Soil alone	3.35	2.95	3.10	3.10				
Soil limed	0.95	0.55	0.45	0.65				
Soybean hay	2.00	2.60	2.60	3.10	−1.35	−0.35	−0.50	+0.00
Limed	0.35	0.95	0.60	0.80	−0.60	+0.40	+0.15	+0.15
Green rape	2.10	2.50	2.65	3.20	−1.25	−0.45	−0.45	+0.10
Limed	0.60	0.80	0.55	0.90	−0.35	+0.25	+0.10	+0.25
Green soybeans	1.85	2.85	2.65	3.00	−1.50	−0.10	−0.45	−0.10
Limed	0.45	0.95	0.55	0.60	−0.50	+0.40	+0.10	−0.05
Oat straw	2.65	2.60	2.65	2.85	−0.70	−0.35	−0.45	−0.25
Limed	0.45	0.75	0.75	0.65	−0.50	+0.30	+0.30	+0.00
Blood	2.00	1.80	2.00	2.95	−1.35	−1.15	−1.10	−0.15
Limed	0.35	0.90	0.65	1.35	−0.60	+0.35	+0.20	+0.70
Blood and 5 tons of straw	1.85	2.65	1.90	3.05	−0.50	−0.30	−1.20	−0.05
Limed	0.35	1.05	0.80	1.50	−0.60	+0.50	+0.35	+0.85
Blood and 10 tons of straw	1.70	2.20	2.05	3.00	−0.65	−0.75	−1.05	−0.10
Limed	0.40	1.20	0.90	1.40	−0.55	+0.65	+0.45	+0.75

It is worthy of note, too, that the organic treatments seem to have increased the capacity of the soil to react with lime, when they were used alone.

There is a rather close correlation between changes in soil reaction, and the nitrogen changes as shown by table 5. This is especially noticeable on the blood treatments where there is sufficient nitrogen added to produce a measurable effect upon the reaction.

These data show a close correlation between the excess of ammonia over nitrates and the true acidity, or pH values of the soils, and would signify that the bacteriological changes which were occurring were affecting the soil reaction to an appreciable extent.

The same thing is shown in table 6 on all treatments, considering the summarized effects as before.

TABLE 5

Difference of ammonia and nitrates on unlimed soils compared with the effect of the treatment on soil reactions

SILT LOAM SOIL	FIRST SAMPLE	SECOND SAMPLE	THIRD SAMPLE	FOURTH SAMPLE
Blood treatment only				
Ammonia (p.p.m.)	270.0	462.0	390.0	378.0
Nitrates (p.p.m.)	7.8	33.8	155.4	366.3
Excess (NH_3) (p.p.m.)	+262.2	+428.0	+234.6	+ 11.7
pH on blood	6.33	7.00	6.46	5.41
pH increase over untreated soil	+1.62	+2.12	+1.68	+0.54

TABLE 6

Nitrogen changes and the effect on soil reaction summarized

ALL TREATMENTS NO LIME	FIRST SAMPLE	SECOND SAMPLE	THIRD SAMPLE	FOURTH SAMPLE
Ammonia (p.p.m.)	169.4	247.9	190.1	179.5
Nitrates (p.p.m.)	26.7	88.2	109.8	242.3
Difference (p.p.m.)	+142.7	+159.7	+80.3	−62.8
pH values	6.01	6.23	5.97	5.17
pH increase over untreated soil	+1.10	+1.35	+1.19	+0.29

TABLE 7

Residual carbonates on treated soils at the various samplings, expressed as tons per acre

	FIRST SAMPLE	SECOND SAMPLE	THIRD SAMPLE	FOURTH SAMPLE	MORE OR LESS THAN SOIL ALONE			
					First sample	Second sample	Third sample	Fourth sample
	tons	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*	*tons*
Clay soil:								
Soil alone	2.35	2.20	1.40	0.90				
Soybean hay	3.15	2.40	1.05	1.05	+0.60	+0.20	−0.35	+0.15
Green rape	3.15	2.10	1.20	0.45	+0.60	−0.10	−0.20	−0.45
Green soybeans	3.25	2.00	1.45	1.00	+0.70	−0.20	+0.05	+0.10
Oat straw	3.20	1.85	1.40	0.95	+0.65	−0.35	+0.00	+0.05
Blood	3.15	3.05	0.60	0.00	+0.60	+0.85	−0.80	−0.90
Blood and 5 tons of straw	3.70	3.20	1.05	0.10	+1.15	+1.00	−0.35	−0.90
Blood and 10 tons of straw	3.60	3.20	0.70	0.00	+1.05	+1.00	−0.70	−0.90

RESIDUAL CARBONATES

The data show that the organic matter protected the carbonates until there was considerable nitrification. All organic treatments caused a marked saving of carbonates at the first sampling. At the last sampling those treatments

where there was much nitrogen to produce nitric acid, nearly or completely exhausted the carbonates present. Even the untreated soil reacted slowly and continually and would perhaps have used up all the limestone after sufficient time, even though there was no leaching.

These data would indicate that excessive nitrification might become a positive factor in contributing to soil acidity. However, nitrates, being soluble, will not accumulate and in the process of leaching basic material is permanently removed from the soil.

HYDROGEN-ION CONCENTRATION

The hydrogen-ion concentration was determined at each sampling on all of the treatments with the hydrogen electrode apparatus.

TABLE 8

Hydrogen-ion concentration

	FIRST SAMPLE	SECOND SAMPLE	THIRD SAMPLE	FOURTH SAMPLE	MORE OR LESS THAN SOIL ALONE			
					First sample	Second sample	Third sample	Fourth sample
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Clay soil	4.91	4.88	4.78	4.88				
Soil alone:								
Soil and 5 tons of lime	7.62	7.72	7.65	7.60				
Soybeans and straw	6.03	5.89	5.50	5.02	+1.12	+1.01	+0.72	+0.14
Soybeans and lime	7.74	7.64	7.41	7.51	+0.12	−0.08	−0.24	−0.03
Green rape	6.03	6.05	6.17	4.78	+1.12	+1.17	+1.39	−0.10
Green rape and lime	7.66	7.65	7.42	7.53	+0.04	−0.07	−0.23	−0.07
Green soybeans	5.81	5.58	5.34	5.17	+0.90	+0.70	+0.56	+0.29
Green soybeans and lime	7.74	7.64	7.60	7.74	+0.12	−0.08	−0.05	+0.14
Oat straw	5.21	5.07	5.41	5.00	+0.30	+0.19	+0.63	+0.12
Oat straw and lime	7.48	7.60	7.66	7.71	−0.14	−0.12	+0.01	+0.11
Blood	6.48	7.17	6.55	5.43	+1.57	+2.29	+1.77	+0.55
Blood and lime	7.71	7.91	7.22	7.60	+0.09	+0.19	−0.43	+0.00
Blood and 5 tons of straw	6.28	7.10	6.58	5.38	+1.37	+2.22	+1.80	+0.50
Blood, 5 tons of straw and lime	7.74	7.76	7.34	7.54	+0.12	+0.04	−0.31	−0.06
Blood and 10 tons of straw	6.24	6.74	6.24	5.44	+1.33	+1.86	+1.46	+0.56
Blood, 10 tons of straw and lime	7.65	7.76	7.36	7.61	+0.03	+0.04	−0.29	+0.01

The lime requirement according to the Tacke method was a little more than 3 tons. To take care of acids which might be produced in the decomposition of organic material, an excess of 2 tons was used. The data (table 8) show that this was sufficient to give a slightly alkaline soil either with or without organic treatment (the smaller the pH value the more acid the soil). Every organic treatment without lime diminished the true acidity of the soil, the highly nitrogenous materials most, as was true also of the lime requirement. The oat straw had the least effect. In the presence of lime, however, the organic treatments had a rather slight effect in reducing the hydrogen-ion concentration at first, and by the third sampling the effect was the reverse in

nearly every case, though again the increase in hydrogen-ion concentrations was not large. By the fourth sampling the effects were quite erratic. In nearly every case where lime was not used, however, the organic treatments reduced the acidity somewhat.

GENERAL DISCUSSION

The materials used in this study were such as are common crop residues or fertilizers. The nitrogen content was: oat straw, 1.05; green soybeans, 2.41; green rape, 3.43; soybean hay, 6.63; and dried blood, 13.93 per cent. The 5-ton application of limestone proved to be scarcely enough to take care of the natural soil acidity plus that produced in nitrification as shown by the data.

The lime requirement shown by the Tacke method on this soil was about 3 tons. Shaking and aeration was continued for only 5 hours, however, in this and the remaining work, partly for convenience and partly because of the fact that a limited amount of work had shown that the lime requirement indicated by a 5-hour run was sufficient. When that quantity of lime was added to the soil and allowed to stand for a short time with optimum moisture conditions, a practically neutral reaction was shown by hydrogen-ion determinations.

The results of the effect of carbohydrate materials upon nitrification have a practical bearing which is worthy of consideration. Experience has shown that the plowing under of green manures such as rye, the heavy use of straw, and other refuse, often cause disappointing yields from the crop immediately following. This may result not alone because the crop has exhausted the water supply previous to plowing under, but oftentimes no doubt, because such materials have furnished the soil organisms with easily available sources of energy, and nitrification does not proceed rapidly enough to supply the crop with nitrates. Thus the immediate crop suffers nitrogen starvation, though perhaps later crops might be much benefited.

SUMMARY

1. Oat straw again reduced nitrification and ammonification below that of the untreated soil.

2. A mixture of straw and blood reduced the total nitrogen found in the form of ammonia and nitrates below that of the blood treatment alone. Ten tons of straw with the blood caused a somewhat greater reduction than the 5-ton application.

3. All the treatments reduced the lime requirement indicated by the Tacke method, until nitrification had taken place.

4. Lime-requirement determinations of the limed soils showed that the treated soils were always capable of reaction with more lime, though an excess of 2 tons of limestone had been applied. This shows that the soils

contain acids which are very slowly reactive, and perhaps they will react with limestone beyond their neutral point.

5. The residual carbonates, where blood was applied, were completely exhausted at the last sampling.

6. The hydrogen-ion determinations show that in practically every case the organic treatments reduced the true acidity. In some cases, on the contrary, both lime and organic treatments did not give as alkaline a soil as did the lime alone.

7. Changes in soil reaction especially on the blood-treated soils, follow very closely the deficit or excess of ammonia over nitric nitrogen, indicating that these processes may become factors influencing the production of acid soils.

BUFFERING IN SOILS

Practically all soils possess perhaps some degree of buffering, that is, they are able to react with either base or alkali to a certain extent, without very

TABLE 9

Table showing treatments and the hydrogen-ion concentration increments corresponding

SOIL	ALONE	1000 POUNDS $Ca(OH)_2$	2000 POUNDS $Ca(OH)_2$	4000 POUNDS $Ca(OH)_2$	8000 POUNDS $Ca(OH)_2$	16,000 POUNDS $Ca(OH)_2$	32,000 POUNDS $Ca(OH)_2$
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
A. Muck	4.5	0.2	0.3	0.2	0.6	0.3	0.7
B. Fine sand	5.1	0.1	0.3	0.7	1.0	1.0	0.1
C. Red clay	5.0	0.2	0.2	0.7	0.8	0.7	0.9
D. Coarse sand	5.8	0.6	0.9	0.5	0.4	0.3	0.8
E. Mucky loam	4.6	0.1	0.1	0.3	0.9	1.2	0.5
F. Neutral soil	7.0	0.3	0.3	0.3	0.3	0.2	
G. Alkaline soil	7.9	0.3	0.0	0.0	0.2	0.1	

much change in hydrogen-ion concentration. The degree of buffering and the rate of change of reaction with increasing amounts of base or acid will depend very much upon soil type, as the following data will show.

Five grams each of the soils listed in table 9 were treated with 0.02 *N* $Ca(OH)_2$ equivalent to the various amounts of lime per acre of 2,000,000 pounds of soil, evaporated to dryness on the steam bath, taken up with 20 cc. of water, allowed to stand over night, and the hydrogen-ion concentration determined with a hydrogen-electrode apparatus. The acid-treated soils were managed in the same way, 0.008 *N* H_2SO_4 being used.

The tabulated data show that the rate of change of reaction with increasing increments of lime is very different for the different soils. The muck soil shows the highest buffering and the sand the least, as would be expected. The neutral and alkaline soils do not change very greatly, showing that they have little capacity for buffering against a base.

The data in table 10 show the effect of acid treatments.

As was true of buffering against bases, the organic soils show a greater capacity for buffering against acids. The sandy soil shows less buffering, and the neutral and alkaline soils have great apparent buffering power, perhaps due to the presence of excess bases.

In general, mucky or organic soils should show the highest degree of buffering, clays less, and sands the least. The protein materials of the organic soils, and the acid silicates of clayey soils are doubtless responsible for most of the buffer action of such types. Sands, containing perhaps little of either, are not usually highly buffered.

The highly buffered soils should show not only less change with the first treatments of base or acid but should continue to resist change of reaction longer when larger treatments are given. The initial reaction, of course, will be a factor to consider at this point. But it is worthy of note that the soils *A* and *C*, which are most acid to start with, show the greatest capacity for buffering against acid.

TABLE 10

Treatments and corresponding H-ion concentrations by increments corresponding to treatments

SOIL	ALONE	1000 POUNDS H_2SO_4	2000 POUNDS H_2SO_4	4000 POUNDS H_2SO_4	8000 POUNDS H_2SO	16,000 POUNDS H_2SO_4
	pH	*pH*	*pH*	*pH*	*pH*	*pH*
A. Muck	4.5	0.4	0.2	0.2	0.2	0.4
B. Fine sand	5.1	0.3	0.3	0.5	0.5	0.4
C. Red clay	5.0	0.4	0.2	0.4	0.5	0.4
D. Coarse sand	5.7	1.0	0.4	0.8	0.4	0.3
E. Mucky loam	4.5	0.3	0.3	0.3	0.3	0.3
E. Neutral	7.0	0.1	0.1	0.3	0.3	2.0
G. Alkaline	7.9	0.1	0.0	0.2	0.0	0.0

It might be supposed that since soils tend naturally to become acid the capacity for buffering against acids would be more or less exhausted. It is demonstrated that this is true to a limited extent only. While the first application of acid causes a comparatively large change in reaction, it is observed that there is a marked buffering which continues to be manifested with the highest treatments. The acid soils likewise, however, have a greater capacity for base buffering.

These facts are best brought out by means of graphs (fig. 1), which show the rate of change by the degree of curvature. Soil *A* has a curve much less steep than the other soils, soil *D* having much the most abrupt slope. The acid curves for *B* and *D* reach a final point nearly together, though starting quite widely separated. Soil *A*, which is by far the most acid, never rises to as high an acidity as soil *D*, which is by far the least acid. Soil *A* is a muck, while soil *D* is a sand and this difference in buffering capacity could be predicted, though such an extreme effect may seem extraordinary.

The above data have considerable significance in various ways. They demonstrate what practical experience has already indicated, that soils may

be quite acid when the total lime requirement is measured, and yet have a comparatively low active acidity. Ordinary soil-acidity methods measure the capacity of the soil for decomposing lime rather than its true acidity or hydrogen-ion concentration. Soils high in organic matter may be able to take up large amounts of limestone, when a great part of this acidity has been overshadowed by amphoteric substances.

Highly buffered soils also may permit vigorous bacterial activity, because the buffering effect keeps down the hydrogen-ion concentration to a point

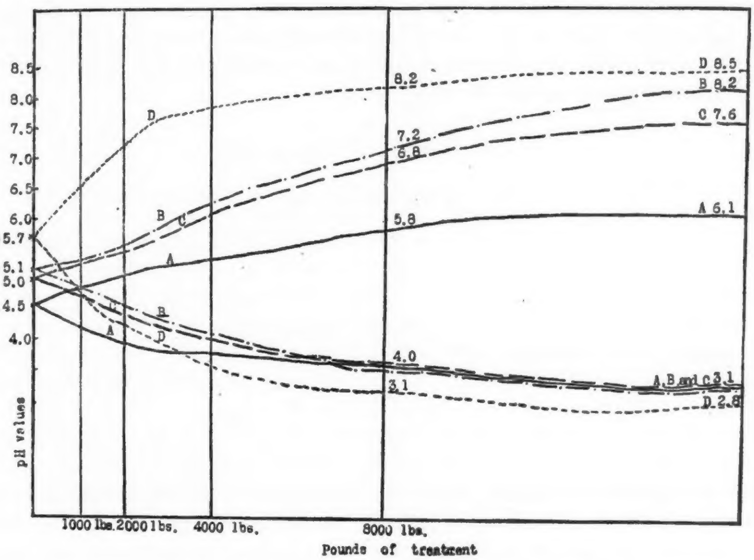

FIG. 1. TITRATION CURVES FOR SOILS A, B, C, AND D, WITH DIFFERENT AMOUNTS OF $Ca(OH)_2$ AND H_2SO_4 ADDED
$Ca(OH)_2$ Curve—upper graph
H_2SO_4 Curve—lower graph

which is not destructive of the soil organisms. A soil on the other hand which is not buffered, has a higher hydrogen-ion concentration though a smaller total lime requirement, and organisms are not very active because of the deleterious effects of the unbuffered acids.

The importance of hydrogen-ion concentration biologically may be shown by the following data taken from Fred's work (2) with legume bacteria. Only the acid limits are given, but perhaps the alkaline limit would be nearly as far above neutrality, which would mean a wide variation for some organisms and only a narrow one for others.

	acid limit pH
1. Alfalfa and sweet clover	5.0
2. Garden pea, field pea, vetch	4.8
3. Red clover and common beans	4.3
4. Soybeans and velvet beans	3.4
5. Lupines	3.2
6. Limits of growth of *Azotobacter* about	6.6 to 8.8

Many soil organisms are even more sensitive to reaction than some of the common legume organisms, and thus the true acidity of soils is doubtless the determining factor for the biological changes which are to occur. No data can be given here for the reaction permitting mold growth, but it is known that they endure high degrees of acidity and probably no soil under ordinary treatment is ever too acid for their activity.

THE NATURE OF SOIL ACIDITY

Hydrogen-ion studies

In the following brief study tumblers of soil treated in various ways were used to determine the effect of the treatment upon the hydrogen-ion concentration. In each case 100 gm. of dry soil were employed, and the moisture content kept at the optimum (50 per cent of saturation). One series was treated with ammonium sulfate at the rate of 1 ton per acre, and lime in increasing increments, 1, 3, 5, 7, 9, 12, and 20 tons per acre of 2,000,000 pounds of soil. The results are given in table 11 in pH values.

The lime requirement of the untreated soil determined by a 5-hour Tacke run was 3.2 tons per acre. It will be observed that the ammonium sulfate alone increased the acidity, as would be expected of a physiologically acid salt which has been nitrified. The increased acidity is not overcome by the 1-ton treatment of calcium carbonate, but is more than overcome by the 3-ton treatment. A neutral reaction is not secured however, until 5 tons are applied when it runs beyond neutrality. After 9 tons are applied there is only a small increase in alkalinity, and with 20 tons the pH is not quite 8.

In table 12 similar results are presented from the tests with an organic nitrogenous material, albumin, applied at the rate of $1\frac{1}{2}$ tons, or approximately the equivalent in nitrogen content of the 1 ton of ammonium sulfate.

The results are very similar to those obtained with ammonium sulfate. Accidentally or otherwise, the albumin caused a slightly greater acidity when lime was not applied to the soil but in most cases it was less. In other words, the same amount of lime permitted less acidity or more alkalinity when albumin was used than when an equivalent amount of ammonium sulfate was used. This may be due to the fact that not only was nitric acid produced from ammonium sulfate but sulfuric acid also remained. When albumin was nitrified if any other acid was produced it was in a smaller quantity or more slightly ionized than the sulfuric acid from the ammonium sulfate.

TABLE 11

The hydrogen-ion concentration values for the various treatments, incubated 6 weeks

	SOIL ONLY	SOIL $(NH_4)_2SO_4$	SOIL $(NH_4)_2SO_4$	SOIL $(NH_4)_2SO_4$	SOIL $(NH_4)_2SO_4$	SOIL $(NH_4)_2SO_4$	SOIL $(NH_4)_2SO_4$	SOIL $(NH_4)_2SO_4$	SOIL $(NH_4)_2SO_4$
Lime..................	0	0	1 ton	3 tons	5 tons	7 tons	9 tons	12 tons	20 tons
pH....................	5.08	4.88	4.98	5.67	7.27	7.86	7.91	7.91	7.96

TABLE 12

Hydrogen-ion concentration values with albumin treatments

	SOIL ONLY	SOIL ALBUMIN	SOIL ALBUMIN	SOIL ALBUMIN	SOIL ALBUMIN	SOIL ALBUMIN	SOIL ALBUMIN	SOIL ALBUMIN	SOIL ALBUMIN
Lime..................	0	0	1 ton	3 tons	5 tons	7 tons	9 tons	12 tons	20 tons
pH....................	5.08	4.76	5.27	6.07	7.84	7.96	7.91	7.91	8.02

TABLE 13

Hydrogen-ion concentration values with various lime applications on soil alone

	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
Lime.........	0	1 ton	3 tons	5 tons	7 tons	9 tons	12 tons	20 tons
pH..........	4.70	4.91	6.55	7.69	7.68	7.90	8.05	8.26

TABLE 14

Hydrogen-ion concentration values of soils treated with acids and varying amounts of lime

	SOIL ONLY	ACIDS AND SOIL	ACIDS AND SOIL	ACIDS AND SOIL	ACIDS AND SOIL	ACIDS AND SOIL	ACIDS AND SOIL	ACIDS AND SOIL	ACIDS AND SOIL
Lime..................	0	0	1 ton	3 tons	5 tons	7 tons	9 tons	12 tons	20 tons
pH....................	4.71	3.91	4.31	6.15	7.25	7.55	7.55	7.69	7.79

TABLE 15

Hydrogen-ion concentration values on soils variously treated as shown

AMMONIUM SULPHATE					ALBUMIN			
Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
$(NH_4)_2SO_4$ only	H_2SO_4 1 ton	H_2SO_4 3 tons	H_2SO_4 5 tons	Citric acid 10 tons	H_2SO_4 3 tons	H_2SO_4 5 tons	Citric acid 7 tons	Albumin alone
4.98	4.21	3.85	3.62	5.22	4.36	3.65	4.69	4.76

TABLE 16

Hydrogen-ion concentration values on soils treated with varying amounts of citric acid

SOIL ONLY	SOIL	SOIL	SOIL	SOIL	SOIL
	Citric acid 3 tons	Citric acid 5 tons	Citric acid 7 tons	Citric acid 9 tons	Citric acid 10 tons
pH	*pH*	*pH*	*pH*	*pH*	*pH*
4.71	5.02	5.33	5.40	5.14	5.33

In table 13 are found the results obtained where the soil alone is given the various lime treatments and the hydrogen ion determined.

Evidently there must have been some variation in the soil as this sample seems to be more acid originally. The 3-ton treatment did not produce neutrality while the 5-ton treatment produced alkalinity. Apparently about 4 tons, or a little more than the indicated Tacke requirement, is necessary to give a neutral soil. The 20-ton treatment runs above $pH = 8$ which is rather alkaline for a limestone treatment.

In the next series acids were added equivalent, respectively, to the nitric and sulfuric acids which would result if the ammonium sulfate were completely nitrified.

The acids increase the acidity but the 5-ton treatment of limestone gives a somewhat alkaline soil (table 14). The higher treatments do not cause as great an alkalinity as where nothing but lime is added to the soil, even when a large excess of lime is present. Another series was treated with ammonium sulfate and mineral and organic acids. Sulfuric and citric acids were used in equivalent amounts.

It is very evident that the 10 tons of citric acid in conjunction with the ammonium sulfate did not increase the true acidity of the soil (table 15). In fact, it is much less. Neither did the 7 tons used with the albumin cause any increase. But the sulfuric acid evidently caused quite a marked increase in every case, the increase being somewhat proportional to the amount applied. The 3-ton application of sulfuric acid did not have so great an effect in the presence of albumin as with ammonium sulfate, but the 5-ton treatment had nearly as great an effect.

Another series was run in which citric acid was used on the soil alone.

It is very evident again that the organic acid has not increased the acidity of the soil, and the largest application has no more effect than the smaller ones (table 16).

These results are in accord with the contention that organic acids do not accumulate in soils under conditions favorable to crop production. It is very evident that the organic acid used here has oxidized rapidly enough to remove all cause for suspicion that ordinary acid soils might owe this characteristic to citric acid produced from the decay of organic matter. The results agree also with those of Stemple, who used citric, oxalic and acetic acids. It is possible, of course, that more stable and active organic acids than citric might be produced, and that there might be conditions when such acids would contribute to the causing of an acid soil.

SOURCE OF ORGANIC AND MINERAL ACIDS

From whence arises the acidity of ordinary agricultural soils has long been a somewhat perplexing problem. It is generally believed at the present time that most of the acidity, except perhaps that in peat and muck soils, arises from some mineral source. The leaching of bases and the consequent accumu-

lation of acid silicates and alumino-silicates is doubtless responsible for a considerable portion of acidity. The practice of using certain commercial fertilizers, such as ammonium sulfate, has caused an acid condition of some soils. Thus the accumulation of sulfuric, hydrochloric, or nitric acids even in small amounts could cause a marked increase in the harmful effects of an acid soil, because such acids are highly ionized and would therefore give a high hydrogen-ion concentration. A small amount of such acids would undoubtedly do more injury than larger amounts of either acid silicates or organic acids.

It may be easily demonstrated that soils contain acids of very variable strengths, the more active ones reacting at once and the very slowly active ones only after a much longer period of contact with limestone and water.

TABLE 17

Lime requirement at intervals of 3 hours

SOIL NUMBER		3 HOURS	6 HOURS	9 HOURS	TOTAL
1	Loam (lbs.)	5000	6100	6500	6500
	Increase (lbs.)		1100	500	
	Per cent of total	77.0	17.0	6.0	100
3	Sandy loam (lbs.)	3700	5100	6200	6200
	Increase (lbs.)		1400	1100	
	Per cent of total	59.7	22.6	17.7	100
4	Sand (lbs.)	800	1100	1100	1100
	Increase (lbs.)		300	0	
	Per cent of total	72.7	27.3	0	100
5	Miami silt (lbs.)	1800	2300	2500	2500
	Increase (lbs.)		500	200	
	Per cent of total	72.0	20.0	8.0	100

This may be due to the fact that the acids are very slowly soluble, or it may be partly because of hydrolytic actions which take place slowly. The data in table 17 showing the varying degrees of activity of soil acids, are taken from a previous work.

These results show that from 60 to 80 per cent of the acidity based upon a total 9-hour run, reacted during the first 3 hours, while there yet remained 6 to 18 per cent to react during the last 3 hours of the run, except for the sand which was not very acid. Determinations have been conducted a much longer period than this and have been found to react slowly even after several days. One muck soil with a lime requirement of 15,200 pounds at the end of 3 hours gave a 25,400-pound requirement at the end of a 23-hour period. A soil of this type, however, is quite different from the ordinary soil, and doubtless the organic acids have a part to play in its reaction.

THE LOSS OF BASES BY SOILS

It is not presumed that soils become acid so long as they contain bases equivalent to the acids. But the question may arise, do acids increase in quantity or do bases diminish in quantity and thus leave a surplus acidity, and if either or both changes take place in what manner do they occur?

The bases such as sodium, potassium and calcium must be held originally in some chemical combination, undoubtedly with a silicate or alumino-silicate, to form a salt or acid salt. This gives a salt of a strong base and a weak acid and should therefore by hydrolysis give up a free base. That such is true has been demonstrated experimentally as shown by the data from Steiger's work (1) with various natural silicates (table 18).

TABLE 18

Alkalinity of natural silicates

NAME	FORMULA	COMBINED ALKALI	EQUIVALENT OF NaO IN SOLUTION
		per cent	*per cent*
Pectolite......	$Ca_2(SiO_3)_3NaH$	9.11	0.57
Muscovite....	$Al_3(SiO_4)_3KH_2$	10.00	0.32
Natrolite......	$Al_2(SiO_4)_3Na_2H_4$	15.79	0.30
Lintonite......	$Al_6(SiO_4)_6(CaNa_2)_37H_2O$	5.92	0.29
Phyogopite....	$Al(SiO_4)_3Mg_3KH_2$	9.32	0.22
Laumonite....	$Al_2SiO_4Si_3O_8Ca4H_2O$	1.00	0.18
Lepidolite.....	$KHLiAl_3(SiO_4)_3K_3Li_3(AlF_2)Al(Si_3O_8)_3$	13.00	0.18
Elaeolite......	$Al_3(SiO_4)_3Na_3$	21.17	0.16
Henlandite....	$Al_6(Si_3O_8)_6(CaNa_2)_316H_2O$	2.00	0.13
Orthoclase....	$KAlSi_3O_8$	16.00	0.11
Analcito......	$NaAl(SiO_3)_22H_2O$	14.00	0.10
Oligoclase.....	$AlNaSi_3O_8Al_2CaSi_2O_8$	9.18	0.09
Albite........	$AlNaSi_3O_8$	12.10	0.07
Wernerite.....	$Ca_4Al_6Si_6O_{25}Na_4Al_3Si_9O_{24}$	11.09	0.07
Leucite.......	$KAl(SiO_3)_2$	21.39	0.06
Stibite........	$Al_2(Si_3O_8)_2(CaNa_2).6H_2O$	1.00	0.05
Chabazite.....	$Al_2SiO_4Si_3O_8(CaNa_2).6H_2O$	7.10	0.05

These results were obtained by placing 0.5-gm. samples in 500 cc. of water and maintaining at a temperature of 70°C. for a month. It is to be expected that in the soil it might go on even more readily, since the base would be leached as liberated unless perchance it reacted with some acid or protein decomposition product to form an insoluble salt. Why all bases do not leach with about equal readiness cannot be stated, but potassium seems about the least readily leached and calcium most readily leached. When several hundred pounds of limestone may be leached out in a single year it is not strange that a soil may become rather acid and unproductive in time for that reason.

There is, therefore, nothing more logical than that with increased weathering there should come increased acidity. As long as base-rich minerals are tightly

cemented together or enclosed within the interstices of a resistant granite or other mineral, they are mechanically protected and saved from waste. But they are likewise saved from any useful function in the soil either as direct plant-food or as a neutralizing agent. Virgin soils are not only more likely to contain many minerals rich in unleached bases but they contain much organic matter in the process of decay and therefore in a condition to react with, and to prevent the leaching of base. With the exhaustion of the organic matter there is the accompanying loss of base and therefore a non-productive sour soil.

Experimental data show that practically any type of soil may become acid. But the acidity of different soil types behaves in a different way, as may be shown also experimentally. A sandy soil is likely to become acid readily because there is not sufficient organic matter to prevent leaching of such bases as may occur naturally or may be applied artificially.

There would probably be little acidity due to organic acids, because there would likely be very little organic matter in such a soil and because conditions would probably be very favorable to the oxidation of such organic acids as might possibly develop. Mineral acids such as the acid silicates, and the stronger sulfuric and hydrochloric acids from the application of certain fertilizers, would likely cause the injurious soil reaction. On a clay soil more acid alumino-silicates would be probable. Loam soils and those of yet higher organic content might contain organic acids, or at least organic compounds capable of combining with base. Such soils remain productive in spite of such acidity as may develop because necessary bases for plant growth have been prevented from leaching and because the organic matter itself is an important source of the essential plant-food, nitrogen. In the growth of legumes, however, it is perhaps not a question of nitrogen content, but more likely a question of reaction and a supply of mineral plant-food, including not only the bases potassium and calcium, but also phosphoric acid.

GENERAL DISCUSSION

There are many factors which influence directly or indirectly the reaction of soils. It is not alone a question of the production of acids but a question of the capacity of the soil to resist changes in reaction caused by the acids produced.

Buffering may be effected by both mineral and organic compounds. Silicates of bases would be capable of neutralizing strong acids, which is in fact a buffering effect. Some of the alumino-silicates no doubt react with either acid or base and therefore function doubly, saving base and reducing the true acidity. The amino acids and many more complex products of protein degradation react in the same manner. The ionization constants for the amino acids as either acids or bases are very low but of about equal strength, making them ideal buffers. This explains why organic soils and clayey soils should show greater power to resist changes in reaction.

Grain size is of course an important factor in determining its reaction, especially with mineral soils. The smaller the grain size the more difficult it is to prevent water-logging, and therefore the more difficult to maintain conditions favorable to the oxidation of organic acids or other harmful products. Though coarse-grained soils readily become acid it is perhaps usually with a somewhat different type of acidity. Rahn (3) has already demonstrated the close relationship between grain size, moisture content, and bacterial activity. This relationship has its influence also upon reaction changes.

SUMMARY

1. Highly organic soils and clays exhibit a high degree of buffering, while coarse sands show little of this capacity.

2. Sulfuric acid, or physiologically acid salts such as ammonium sulfate, cause a change toward increased hydrogen-ion concentration in soils. Citric acid did not increase the true acidity.

3. Ammonium sulfate caused a greater increase in acidity than did its nitrogen equivalent of albumin.

4. When nitric and sulfuric acids were added to the soils in amounts equivalent to the acidity which might be produced from the complete nitrification of ammonium sulfate, a greater increase was produced in the hydrogen-ion concentration of the soil than where the ammonium sulfate was used.

5. A large excess of pure lime carbonate (20 tons) brought the pH value to only a little more than 8.0, which seems to be about the limit of alkalinity produced by limestone.

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THE ROLE OF OSMOTIC PRESSURE IN THE TOXICITY OF SOLUBLE SALTS

J. E. GREAVES AND YEPPA LUND

Utah Agricultural Experiment Station

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The following brief résumé of the literature shows that many investigators consider the toxicity of soluble salts toward bacteria and higher plants to be due mainly to an osmotic effect. Stolgane (23) found that plants could resist only a comparatively low osmotic pressure, which, when not exceeding two atmospheres, stimulates growth. However, all the vegetative processes including growth may be checked entirely if the pressure becomes much higher than two atmospheres.

Ewart (7) found that heavy dressings of salt retarded the germination of seeds and in some cases caused them to rot in the soil. The injurious action of the salt he attributed mainly to osmotic influences.

Maliuschitskii (19) grew cereals in sand cultures with a normal nutrient solution to which were added various compounds of calcium, magnesium, sodium and potassium, comparison being made between each individual salt. In one set the solutions were isotonic, whereas in the other series the strength of the solutions was raised to the same degree of isoconcentration. He found that when isotonic solutions were used the plants resembled one another in external appearance in the amount of dry matter and in anatomical characters as well as in the percentage of nitrogen they contained. When, on the other hand, plants were grown in isoconcentrated solutions, especially in the case of such salts as magnesium sulfate and sodium chloride, the plants differed not only in their nitrogen content but in other respects. Similar results were obtained later with sugar-beets, oats and millet.

Beauveria (4) observed that the structure of *aspergillus*, *phosealus*, *pesun*, *lupinus*, *zea*, and *triticum* were modified by changes in osmotic pressure.

Hill (15) studies various salt-marsh plants to find the effect of differences in the salinity of the soil upon the plants and how the plant accomodates itself to the fluctuating concentration of the soil water.

The results indicated that the root-hairs of *salicorna*, growing in places where the soil water is strongly saline, can adapt their internal osmotic pressure to the osmotic strength of the soil solution. On transferring isolated seedlings from relatively strong saline solutions to fresh water, the tips of the root-hairs were found to swell and assume abnormal shapes. Branching was also occasionally seen. The cellulose walls of the tip of the root-hair under

some conditions became thickened. This he believed to be of value in giving the end a greater strength in order to protect against a sudden increase in the internal pressure.

According to Tulaikov (24) soluble non-nutritious salts of the soil have a noteworthy influence on vegetation from the first stages up to harvest. At germination the non-nutrients appear to exercise an essential physical action in modifying osmotic pressure, thus regulating the absorption of water by the germinating seeds. Isotonic solutions of different salts have an almost equal action. The toxic effect of the different salts on seedlings of various plants is in general due to plasmolysis. In some cases there is a chemical action since the tissues of the root system are destroyed or its superficial cells modified.

Barnes and Ali (3) consider the changed osmotic pressure to be the main cause of injury to plants and even bacteria caused by alkali salts, as seen from the following:

> From our own observations we conclude that the salts' presence in alkali soils does not exert any toxic effect on the plant. The effects produced are purely physical. . . . . The danger point is reached when the osmotic pressure of the saline solution becomes equal to that of the cell sap. This is irrespective of the nature of the salt, provided it possesses no toxic properties; such salts as the sulfates and chlorides of sodium or calcium exhibit no toxicity to plant protoplasm. Even carbonate of soda cannot be said to be toxic in the present state of our knowledge, though we know that it shows evidence of caustic action on the stems of plants growing in soils affected by the salt. Whether the caustic effect is produced on dead or living tissue is not known. But as soon as the osmotic pressure of the fluid entering the root tips from the soil becomes greater than that of the cell sap, the protoplasm of the cell shrinks away from the containing walls and the plant loses its turgidity and becomes flaccid. It shows in fact all the appearance of withering. and if the concentration of the external fluid is not immediately reduced by dilution the plant dies. Dilution of the saline solution is in itself a remedy at this stage, and this is one reason which leads us to believe that the salts possess no toxic properties and that their effect is a purely physical phenomenon.

Hansteen (12) found that magnesium, sodium, and potassium salts in the cultural fluid caused the roots of wheat to shrivel and die, whereas the presence of calcium salts increased the root growth. The magnesium ions were the most toxic, but he found that neither temperature, osmotic pressure, nor the anions present influenced the toxicity.

Harris (13) found there was little relationship between the molecular weight of a compound and its toxicity to wheat seedlings and he therefore concludes that the osmotic pressure is not the controlling factor in the toxicity of the common soil alkalies.

Klebs (16) and other workers found that many green algae were capable of existing in two or more forms, but the stimuli inducing the change were unknown. Livingston (17), however, showed that it was the osmotic pressure of the solution in which the algae grew. He demonstrated that the response of *Stigeoclonium tenue*, both in form and in reproductivity, which

accompanies a change in concentration of Knop's solution in which it is growing, is due to changes in the osmotic pressure of the medium and is in no way a function of its chemical composition. Further work (18) demonstrated the fact that solutions of non-electrolytes produce the same results as those of electrolytes, for in them, also osmotic, is the controlling factor in determining the form of the plant. This is effective through changes in the water content of the cells.

Livingston (18) found that a high osmotic pressure influences the plant in four ways: (a) it decreases vegetative activity; (b) it inhibits the production of zoospores; (c) it causes cylindrical cells to become spherical; and (d) it frees the algae from certain limitations as to the orientation of the planes of cell division. Conversely, a low pressure reverses these effects. It was also ascertained that there were certain quantitative differences between the concentrations required to inhibit zoospores in the palmella and in the filamentous stage, those required for the former being the greater. Between the behavior in this respect of electrolytes and of non-electrolytes, such as sucrose, quantitative differences were found.

Atkins (2), however, considers it improbable that all these phenomena are due merely to variations in the amount of water in the vacuoles. He considers it associated with the alterations in the state of inhibition of the protoplasmic colloids, also with changes in the rate of oxidations which normally occur in the cell, owing to increases or decreases in the area of external surface, and consequent disturbance of the usual rate of intake of atmospheric oxygen. Artari (1) is also of the opinion that various salts have other effects upon algae than the osmotic.

Many bacteria lose their motility when brought into solutions of a high osmotic pressure, and Wladimeroff (25) has employed this arrest of motility to measure osmotic pressure.

Barnes and Ali (3) consider that bacteria are subject to the same physical laws of molecular pressure in solution as the higher plants or the dead membrane of the physicist's instrument, and hence are destroyed by osmotic changes.

THEORIES AS TO TOXICITY

Overton (22) considered inorganic salts incapable of penetrating living cells, but Osterhout's experiments (21) on spirogyra clearly demonstrated that they do. He further found that sodium chloride and other salts of monovalent metals increase the permeability of protoplasm, whereas calcium chloride and the salts of other divalent metals have just the opposite effect. Where cells are placed in a mixture of the mono- and divalent salts there is a mutual hindrance of each salt upon the entrance of the other into the cell; hence, the toxic action of each salt upon the protoplasm is diminished by the presence of the other, because their rate of penetration into the protoplasm is greatly reduced.

Some ions on entering the cell may produce a colloidal precipitate in the root cell and this either retards the growth or causes the death of the plant, depending upon the nature and concentration of the medium.

De Lavison (6) found that for weak solutions cations of alkalis and alkaline earths combined with non-toxic anions penetrated the protoplasm with difficulty. Certain salts of aluminum and yitrium and a large majority of the salts of the heavy metals do not penetrate the living protoplasm. He held that the permeability of the protoplasm to weak solutions is an absolutely different phenomenon from its permeability by strong solutions. The protoplasm under the influence of strong solutions becomes completely permeable, without, however, being killed by those salts which in weak solutions are unable to penetrate it. He claims to have established two facts as to toxicity of salts.

(a) The toxic action of a molecule is approximately a property of acid and basic radicals for a large number of salts, while this is due to properties acquired by the molecule by reason of its non-saturation by the acids and bases.

(b) The toxic salts are those which do not penetrate at all or only with difficulty the living protoplasm when they are employed in weak solutions, whereas solutions of non-toxic salts, on the contrary, easily penetrate the protoplasm. The protoplasm seems to be an unstable substance as regards a large number of salts.

Undoubtedly the action produced varies with the specific salt. Fluri (8) considers that aluminum salts act upon the diastase, thus reducing the production of starch. There may even be a different effect exerted by the negative or positive ion of the same salt. Nabokich (20) found that the anions of most compounds produce a strong acceleration, whereas the cation hinders or limits growth.

It is quite evident from the preceding brief review of the physical, chemical and colloidal theories which have been offered for the toxicity of salts that many workers lean to the physical with the dominant idea that in many cases at least the predominating factor is an osmotic phenomenon, and it became evident to the senior author of this paper early in his study of the influence of soluble salts upon the bacterial activities of the soil, that while the osmotic pressure, plays an important part in the toxicity of most salts to bacteria, yet the physiological influence exerted upon the protoplasm of the cell is not to be ignored.

METHOD OF INVESTIGATION

The toxicity of the chlorides, carbonates, nitrates and sulfates of sodium, potassium, calcium, magnesium, manganese and iron to ammonifying and nitrifying bacteria was determined by the regular beaker method (9, 11). From the data thus obtained we were able to compare the compounds as to toxicity from three viewpoints: (a) the lowest concentration of the salt at which a toxic effect is noted toward the ammonifying and nitrifying organisms

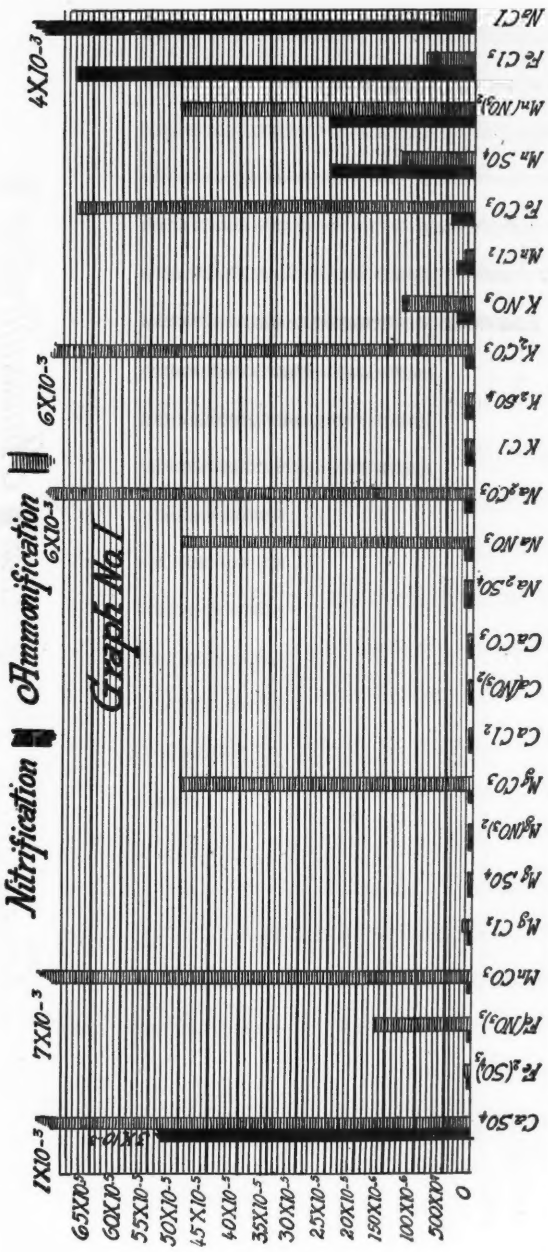

FIG. 1. GRAPHS SHOWING THE MOLECULAR CONCENTRATIONS AT WHICH THE VARIOUS SALTS ARE TOXIC TO AMMONIFYING AND TO NITRIFYING ORGANISMS

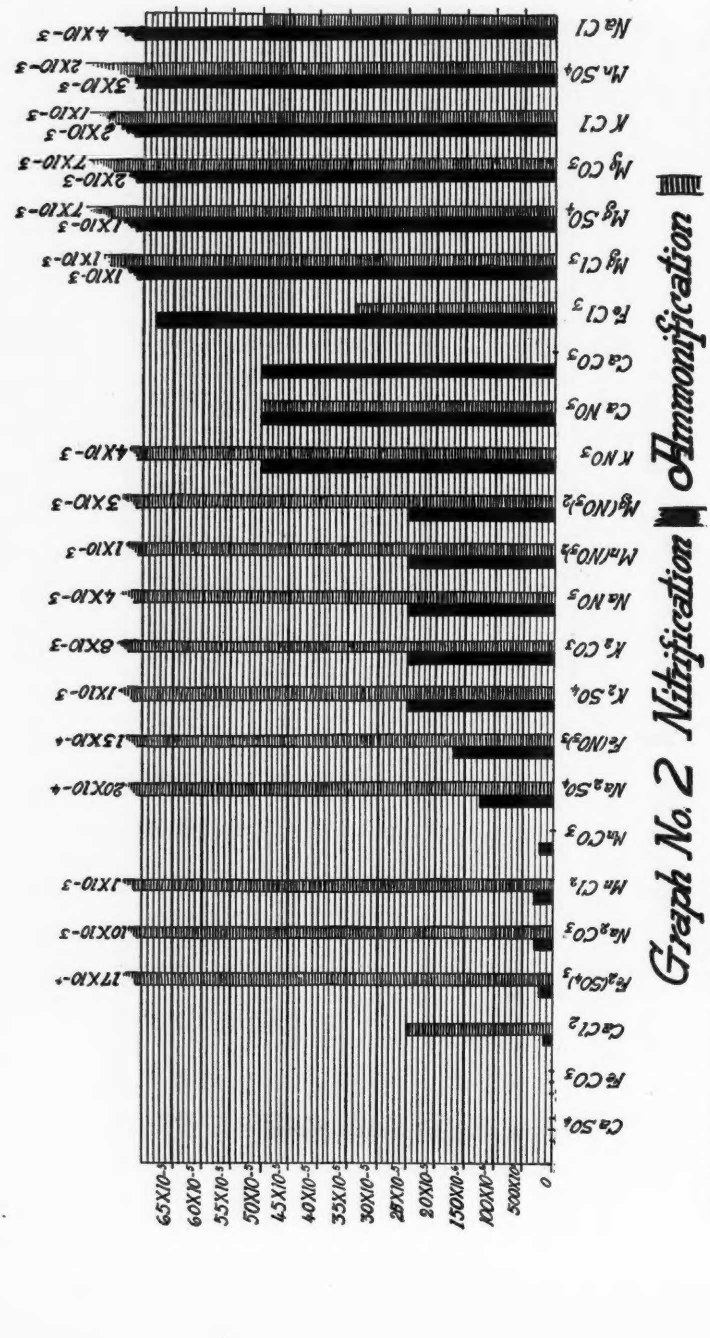

Fig. 2. Graphs Showing the Molecular Concentrations at Which Ammonification and Nitrification are Reduced to About Three-Fourths Normal

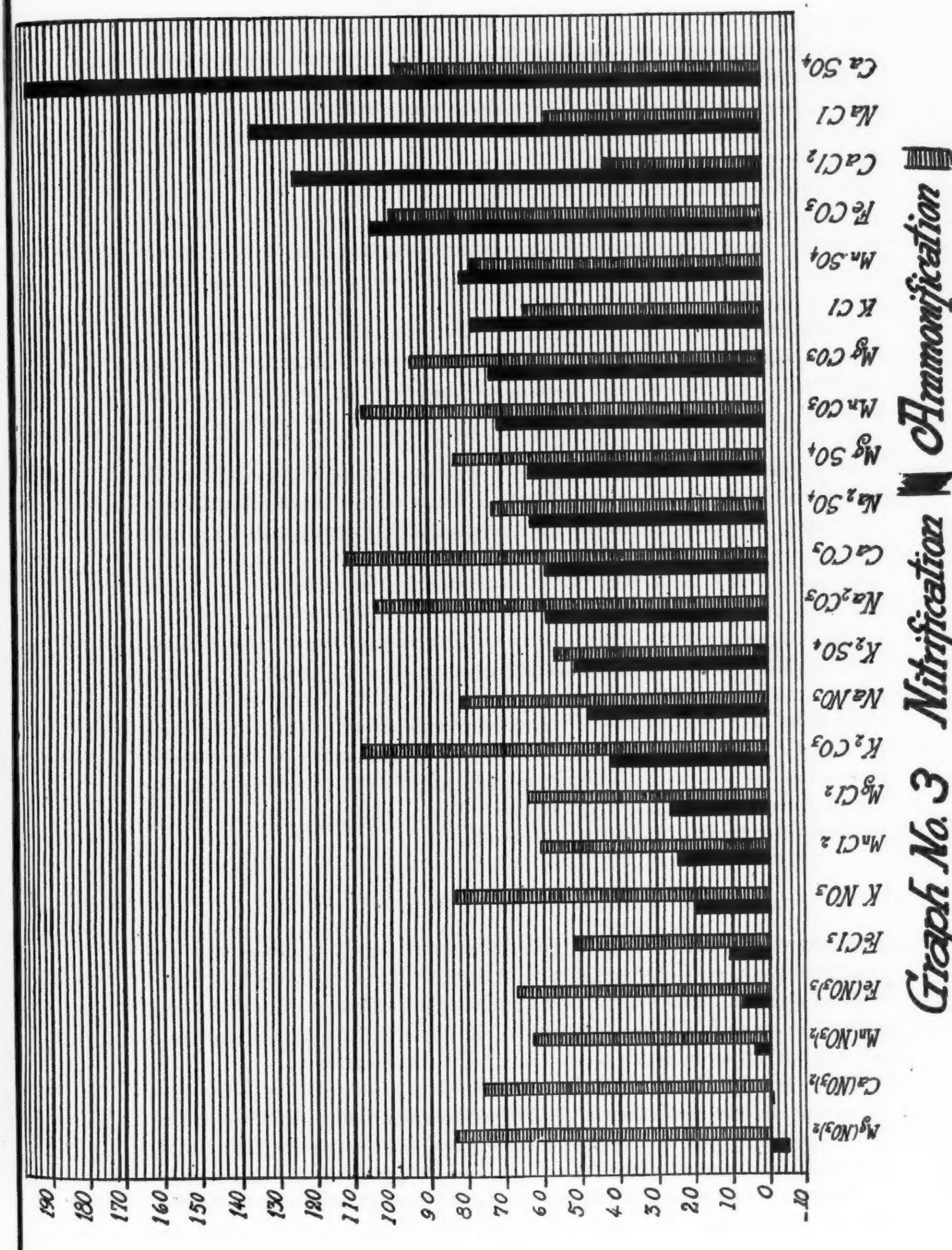

FIG. 3. GRAPHS SHOWING THE PERCENTAGES OF AMMONIA AND NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL TO WHICH HAD BEEN ADDED 2×10^{-3} M OF THE VARIOUS SALTS, THE UNTREATED SOIL BEING COUNTED AS PRODUCING 100 PER CENT

(fig. 1); (b) the molecular concentration at which ammonification and nitrification were reduced to three-fourths normal (fig. 2); and (c) the percentages of nitric nitrogen and ammonia produced in the presence of the largest quantity of the various salts, which is 2×10^{-3} *M* of the salt in 100 gm. of soil (fig. 3)

Not one of the compounds tested was toxic at the lowest concentration—78×10^{-7} *M*. All became toxic at some of the concentrations tested. In eleven out of the twenty cases the point of toxicity for the ammonifiers and nitrifiers was the same, whereas in the remaining cases the quantity required to become toxic to the ammonifiers was much greater than it was for the nitrifiers. In only three instances were the salts more toxic to ammonifiers than to nitrifiers.

A relationship between the toxicity of the compound and its power to precipitate colloids was not found. It appears, therefore, that while the precipitation of the colloidal cellular material often causes the death of the organisms, it is not necessarily the determining factor in the toxic action of these salts.

As can be seen from figure 3, it is not necessarily these compounds which become toxic at the lowest concentration which have the most far-reaching effect upon the bacterial activities of the soil. This condition holds for both the ammonifying and nitrifying organisms. It requires in almost every case more of the specific salts to reduce ammonification to three-fourths normal than is required to produce the same effect upon the nitrifiers.

The osmotic pressure of the soil is not necessarily directly proportional to the quantity of salt added to the soil, as some salts may ionize to a greater extent than others. Moreover, the addition of a salt to a soil changes materially its soluble constituents (10), and hence may either increase or decrease its osmotic pressure. Therefore, measurements were made of the osmotic pressure of the soil under as nearly as possible the same conditions as maintained when bacterial activity was determined. This was done by means of the cryoscopic and conductivity methods.

Cryoscopic method

One-hundred-gram portions of the soil were mixed in tumblers with the quantity of salts indicated in figures 1, 2, and 3. To these were added 2 gm. of dried blood and their moisture content brought to 18 per cent. These were allowed to stand in covered tumblers for 12 hours and then transferred to a tin tube (*2*, fig. 4), in which the freezing point was determined.

The determinations were made by the method as outlined by Bouyoucos (5) except that we used ether in place of ice for the freezing of the soil. The ether was evaporated from a glass container insulated with kieselguhr (fig. 4) by drawing air through *3* by means of a tube, *4*, connected with an air pump.

Ether was economized by conducing cold air through tube 3 from the outside of the building. The tubes containing the soil were placed in an ice-salt

mixture before placing in the ether, thus removing the greater excess of heat before attempts were made to freeze. By following this procedure it was found possible to freeze a sample of soil with half an ounce of ether. This method has the advantages over the regular ice-salt mixture in being easier

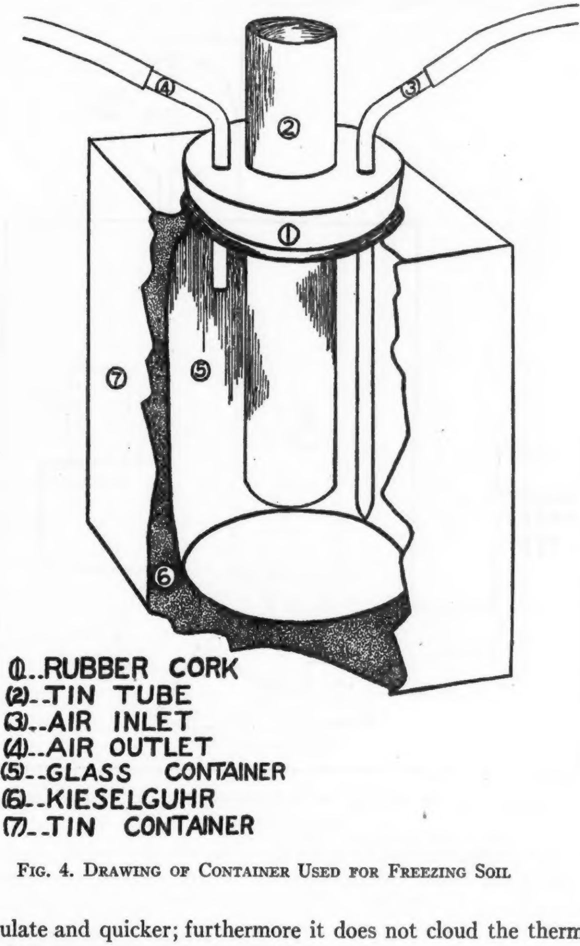

FIG. 4. DRAWING OF CONTAINER USED FOR FREEZING SOIL

to manipulate and quicker; furthermore it does not cloud the thermometer, thus permitting a more accurate reading.

In commencing a determination it was found advisable to have the temperature of the ether not lower than $-2°C.$; otherwise, the soil will not supercool, and hence the freezing point cannot be accurately read.

Conductivity method

The soil was prepared as in the cryoscopic method and the conductivity determined as outlined by Hibbard (14). The apparatus used was a transformer, an alternating current galvanometer, a bridge, a Curtis coil, and resistance box. The scheme of connection is given in figure 5.

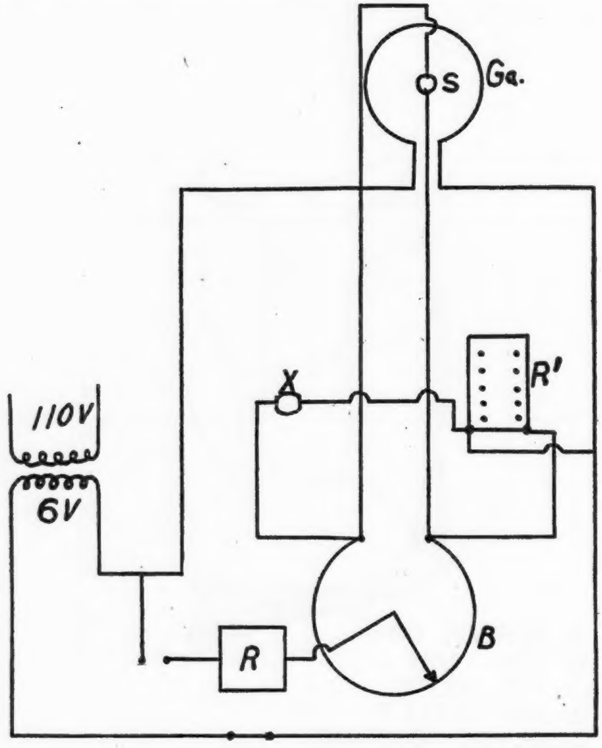

FIG. 5. SCHEME SHOWING METHOD OF CONNECTING APPARATUS FOR DETERMINING CONDUCTIVITY

B—Wheatstone bridge; *R*—resistance coil for cutting down current; *R'*—known resistant coil; *Ga*—alternating current galvanometer; *S*—movable coil and galvanometer 110 v. to 6 V.

The source of current was the alternating current of the electric light. The terminals which were placed in the soil were made from two spatulas the blades of which were cut to 3 inches and tipped with platinum foil, the remaining part of the blade being covered with a good insulator. The handles were insulated and solidly bound together. These were plunged into the soil of the tumblers. The whole was kept at a constant temperature within 0.01°C.

by means of a thermostat, the outline of which is shown in figure 6. The temperature was held constant for 30 minutes before determining the conductivity. All determinations were made in triplicate, and the results as reported are in every case the averages of six or more closely agreeing determinations.

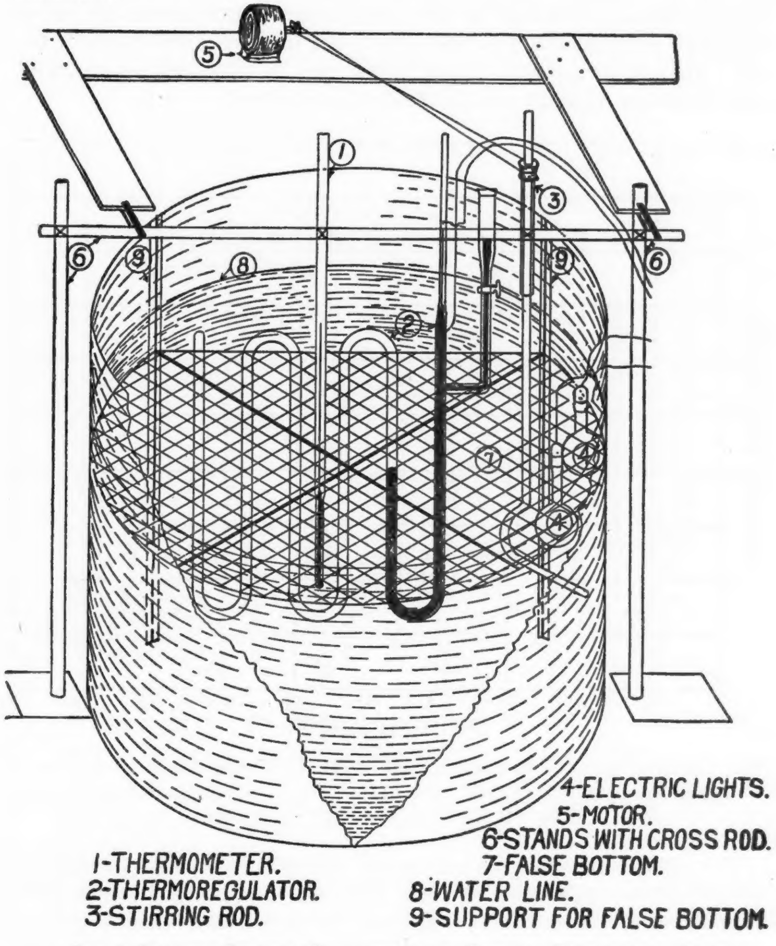

FIG. 6. DRAWING SHOWING CONSTRUCTION OF CONSTANT-TEMPERATURE BATH

AMMONIFICATION

Figure 7 gives the relationship between the osmotic pressure as determined by the freezing-point method and the conductivity method of a soil to which sufficient salt had been added to become toxic to the ammonifying organisms.

On the ordinate is given the per cent of ammonia formed, the untreated soil being taken as 100, whereas on the abscissa is given the osmotic pressure in atmospheres. With the exception of iron chloride the osmotic pressure is higher and slightly more uniform as determined by the conductivity method than by the freezing-point method. Calcium nitrate, manganese nitrate, and sodium carbonate with both methods yield abnormal results, probably due to the action of these salts upon the organic and inorganic constituents of the soil. Throughout the work it would appear that the most reliable and coordinate results are obtained with the conductivity method.

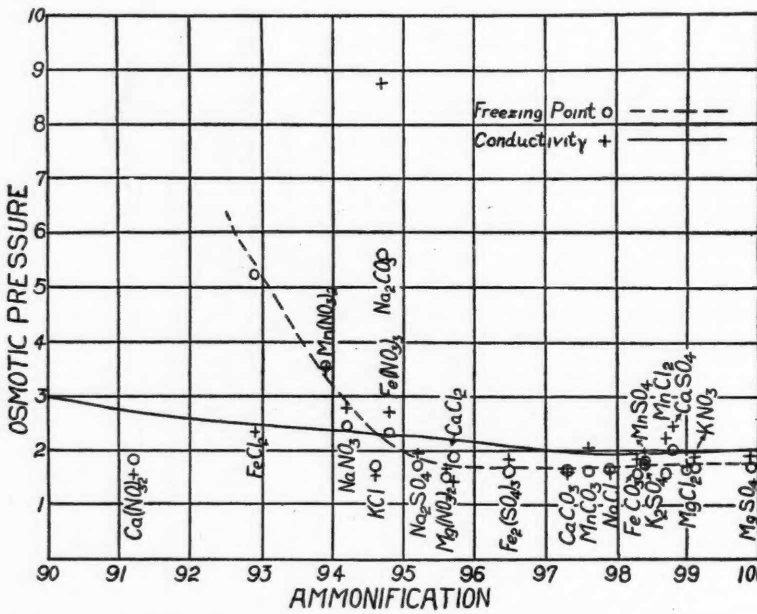

FIG. 7. GRAPHS SHOWING OSMOTIC PRESSURE AND MILLIGRAMS OF AMMONIA PRODUCED IN SOIL TO WHICH THE VARIOUS SALTS WERE ADDED IN QUANTITIES SUFFICIENT TO BECOME TOXIC TO AMMONIFYING ORGANISMS

The other compounds show a marked relationship between the osmotic pressure of the soil solution and the toxicity of the salt toward ammonifying organisms. With the exception of those salts noted, all become toxic when they produce within the soil an osmotic pressure of from 1½ to 2½ atmospheres, thus indicating that the toxicity of these salts is due mainly to increased osmotic effects.

However, as the osmotic pressure of the soil is increased by the addition of the several salts the relationship observed above is not so uniform, as may be seen from figure 8. In this figure is given the percentages of ammonia pro-

duced and the osmotic pressure of soil to which sufficient salt had been added to reduce ammonification to three-fourths normal. Bacteria produce ammonia in a soil the osmotic pressure of which is from 8 to 15 atmospheres, when the osmotic pressure is due to sodium carbonate and the nitrates of magnesium, sodium and iron. When the osmotic pressure is due to the nitrate and chloride of calcium the sulfate and chloride of iron, sodium chloride, magnesium carbonate, potassium chloride, and manganese sulfate, the ammonia production is reduced to three-fourths normal with an osmotic pressure below four

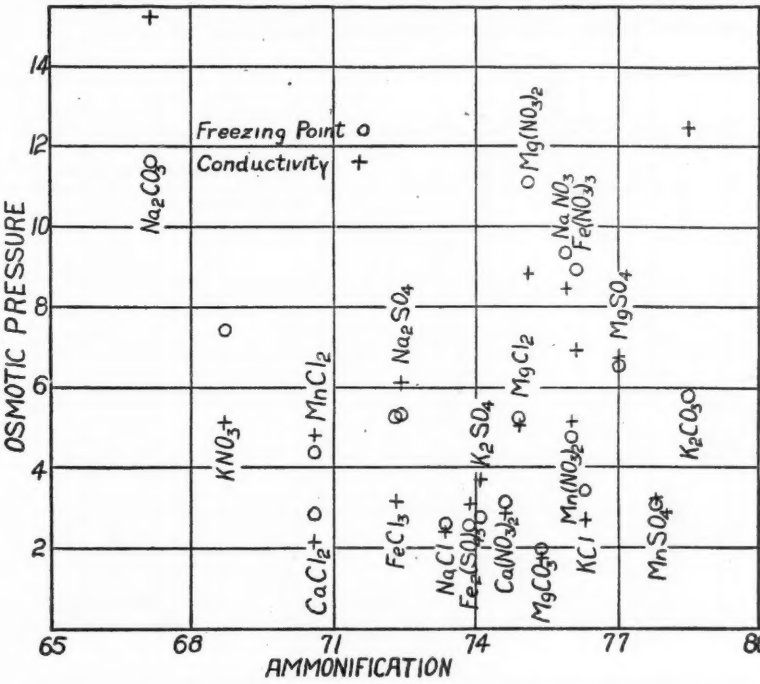

Fig. 8. Graphs Showing Osmotic Pressure and Milligrams of Ammonia Produced in Soil to Which the Various Salts were Added in Quantities Sufficient to Reduce Ammonification to About Three-Fourths Normal

atmospheres. This indicates that whereas the beginning of toxicity of the several salts toward ammonifying organisms is due largely to osmotic pressure, as the concentration of the salt increases other factors enter, but even in very high concentrations there is a striking relationship between osmotic pressure and ammonia produced in the soil, as may be seen in figure 9. It is surprising to find that ammonifying organisms can function in soils having osmotic pressures as high as 45 atmospheres. Under this condition, however, the quantity of ammonia produced is very small.

The results taken as a whole indicate that the toxicity of the several salts examined is due to two factors: (a) the increased osmotic pressure produced by the salt within the soil and (b) a probable physiological action of the substance upon the living protoplasm of the cell changing its chemical and physical properties so that it can no longer function normally. The former factor is probably the more far-reaching. This is the reverse of the early conclusion (9, 10, 11), for the osmotic pressure is not always directly proportional to the salt added but depends upon the kind and degree of association. Furthermore, many salts undergo double decomposition within the soil, thus markedly changing what would otherwise be the osmotic pressure.

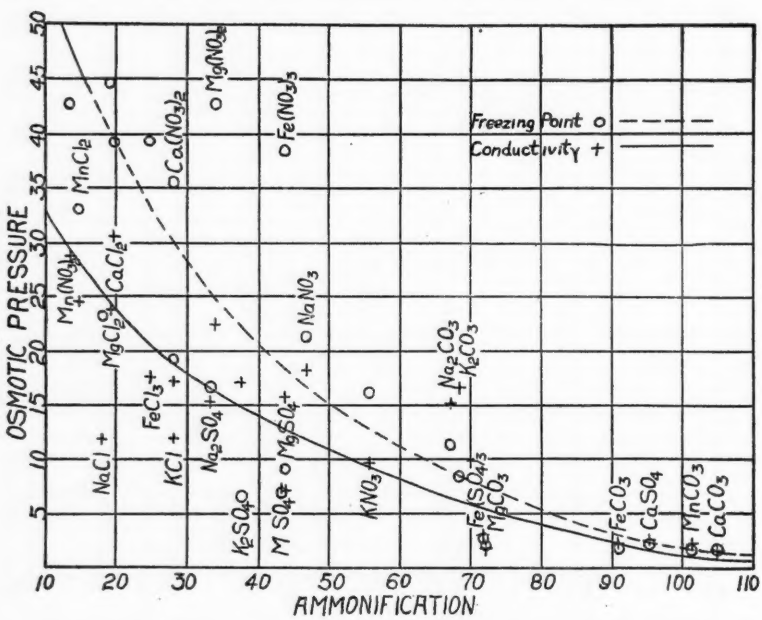

FIG. 9. GRAPHS SHOWING OSMOTIC PRESSURE AND AMMONIA PRODUCED IN SOIL TO WHICH 10×10^{-3} *M*. OF THE VARIOUS SALTS WERE ADDED TO 100 GM. OF SOIL

NITRIFICATION

The osmotic pressure was determined by both cryoscopic and conductivity methods on soil to which sufficient salts had been added, first to become just toxic to nitrifying organisms, second to reduce nitrification to three-fourths normal, and third to produce the highest concentration of the salt which was studied in the nitrification test of toxicity—2×10^{-3} *M* in 100 gm. of soil.

Figure 10 gives the results obtained when sufficient salt was added to become toxic. On the ordinate is given the per cent of nitric nitrogen formed, whereas

on the abscissa is given the osmotic pressure as determined by the two methods. It is quite evident that there is a large difference in the extent to which the various salts reduce nitrification. Some of them yield 100 per cent or above at the one concentration, and at the next concentration tested, a great decrease in nitrification is observed. Yet it is quite evident in the case of most of the salts that there is a relationship between the osmotic pressure of the soil and the toxicity of the several salts—sodium chloride, iron chloride, and manganese nitrate being clearly exceptions. The osmotic pressure at which nearly all salts become toxic to nitrifying organisms is between 1 and 2

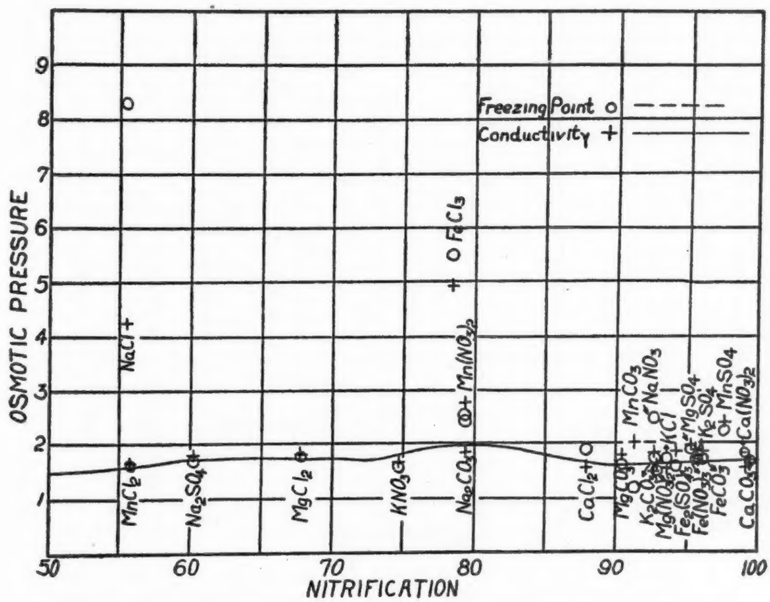

Fig. 10. Graphs Showing Osmotic Pressure and Milligrams of Nitric Nitrogen Produced in Soil to Which the Various Salts were Added in Quantities Sufficient to Become Toxic to Nitrifying Bacteria

atmospheres. In the case of the ammonifying organism it ranges between 1 and 3 atmospheres, usually averaging slightly higher for ammonifying than for nitrifying organisms. As the concentration of the salts increases the difference in sensitiveness of the two groups of organisms becomes more divergent. This may be seen from figure 11. As an average, all of the salts reduce nitrification to about three-fourths normal when the osmotic pressure of the soil ranges between 2 and 3 atmospheres, whereas for ammonification it is considerably higher than this. It is quite evident here also that sodium chloride and iron chloride do not as closely conform in toxicity and osmotic

pressure as do the other salts. The results as a whole, however, point to the conclusion that where the toxicity of the tested salts is due primarily to osmotic effect, yet physiological influences undoubtedly play a part. The latter part of this conclusion is well borne out by the results given in figure 12. Here we find calcium sulfate producing an osmotic pressure of two atmospheres, and still the nitrifying organism produces twice as much nitric nitrogen as in untreated soil. Soil to which sufficient sodium chloride had been

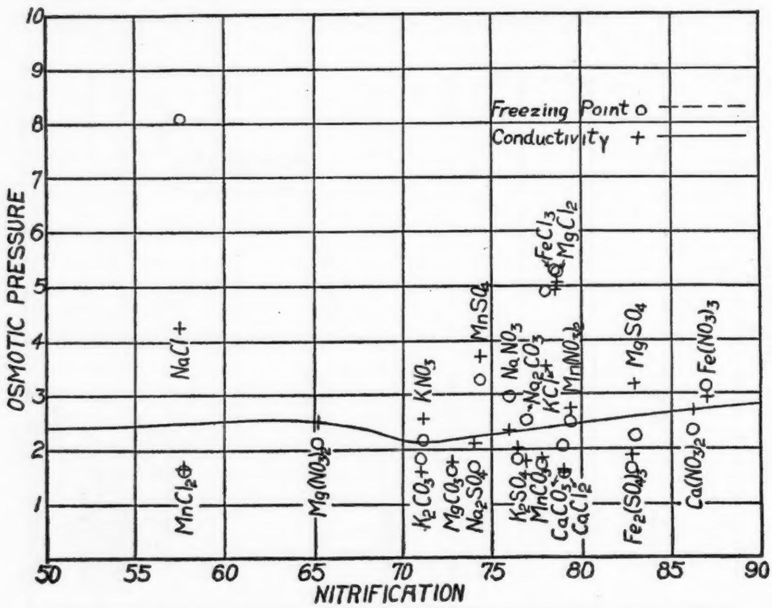

FIG. 11. GRAPHS SHOWING OSMOTIC PRESSURE AND MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN SOIL TO WHICH THE VARIOUS SALTS WERE ADDED IN QUANTITIES SUFFICIENT TO REDUCE NITRIFICATION TO ABOUT THREE-FOURTHS NORMAL

added to produce a like osmotic pressure showed 140 per cent normal nitric nitrogen. Yet a similar osmotic pressure produced by potassium carbonate or potassium nitrate nearly stops nitrification.

It is quite evident that the nitrifying organisms are much more sensitive to osmotic changes than are ammonifying organisms. No nitrates were produced in soils having an osmotic pressure of over 8 atmospheres, whereas ammonification took place to a small degree in soil the osmotic pressure of which was 35 atmospheres.

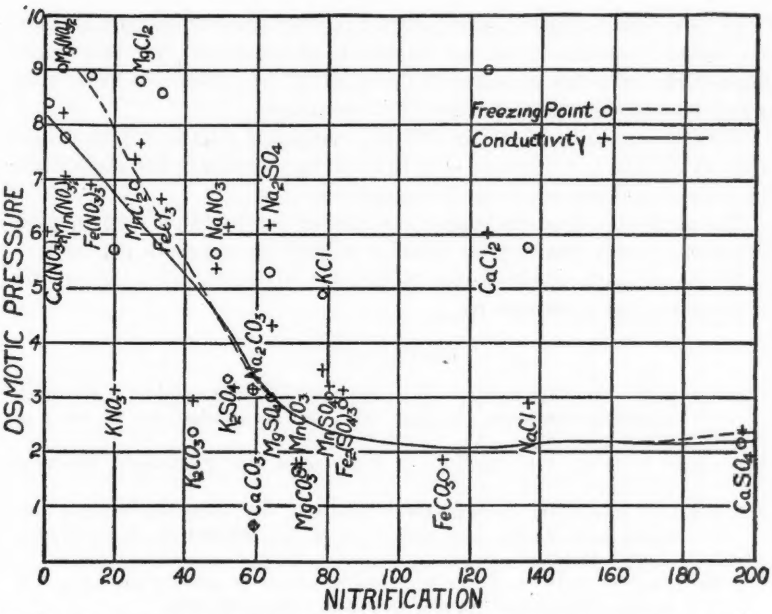

FIG. 12. GRAPHS SHOWING OSMOTIC PRESSURE AND NITRIC NITROGEN PRODUCED IN SOIL TO WHICH 2×10^{-3} *M*, OF THE VARIOUS SALTS WERE ADDED TO 100 GM. OF SOIL

SUMMARY

The osmotic pressure was determined by the cryoscopic and electrical conductivity methods on soil to which the chlorides, sulfates, carbonates and nitrates of potassium, sodium, caldium, magnesium, iron and manganese had been added in quantities such that (a) the salts became toxic to the ammonifying organism, (b) the quantity of ammonia produced in unit time was reduced to three-fourths normal, (c) the concentration of the salt in the soil was 10×10^{-3} *M* per 100 gm. of soil, (d) the salt became toxic to the nitrifying organism, (e) the nitric nitrogen produced in unit time was reduced to three-fourths normal, and (f) there would be 2×10^{-3} *M* of the salt in each 100 gm. of the soil.

With the exception of manganese nitrate, iron nitrate and sodium carbonate there is a close correlation between toxicity and osmotic pressure. All the salts tested, except these three, became toxic when the osmotic pressure was less than 3 atmospheres.

As the concentration of the salt added to the soil increases it is evident that the retarding effect upon the ammonifying organism is not due entirely to the osmotic pressure. There is probably a physiological action of the substance upon the living protoplasm, changing its chemical and physical properties so that it cannot function normally.

All salts tested reduced ammonification to less than one-half normal when the osmotic pressure of the soil reached 15 atmospheres. Yet there were appreciable quantities of ammonia produced in the presence of some salts when the osmotic pressure reached 20 atmospheres.

With the exception of sodium chloride, manganese nitrate, and iron chloride, all the salts tested became toxic to nitrifying organisms when the osmotic pressure ranged between 1 and 2 atmospheres.

The nitrifying organisms behave in a manner similar to the ammonifying organisms, except that they are retarded at much lower osmotic pressures.

All the salts reduced nitrification to less than 50 per cent when the osmotic pressure reached 6 atmospheres.

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THE EFFECT OF FERTILIZER TREATMENTS ON SAVANNAH CRANBERRY LAND[1]

CHARLES S. BECKWITH

New Jersey Agricultural Experiment Stations

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The New Jersey Agricultural Experiment Station has been carrying on fertilizer experiments on cranberry land for 8 years. Before this period the growers were using some commercial fertilizer in rather conservative amounts, but with little idea of the proper proportion of the various ingredients. The station administration felt that it should have definite data to meet the requests for information from the growers. Following an offer of coöperation by the American Cranberry Growers' Association in the spring of 1913 the work was at once begun and has continued to the present time.

THE CRANBERRY BOG

The cranberry plant is so unusual that a few words relative to its culture and management may be necessary for a complete understanding of the fertilizer studies. The cranberry is one of the heath plants native to acid swamps of northern North America. Under cultivation it is grown rather widely throughout the southern part of New Jersey as well as in eastern Massachusetts and in Wisconsin. Before setting out the plants, the ground is cleared of all its natural growth, the stumps and roots are removed and the ground at least roughly leveled. Cranberries are propagated by hard-wood cuttings, set out in squares from 10 to 24 inches apart. The cuttings send out runners which entirely cover the ground and which send up "uprights" bearing fruit buds. The first harvest is on vines 4 years old and after that crops may be expected annually for 50 years. The character of the vines precludes any cultivation in the ordinary sense of the word.

Cranberry bogs are submerged in winter from December to the first week in May to prevent winter injury, to control certain insect pests and to secure an even start of the vines in spring. They are "reflowed" usually about the first of June to control other insect pests. Flooding for frost protection is practiced as often as the weather demands. After harvest the bogs are put under water for a week for cleaning up various pests.

[1] Paper no. 25, of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Entomology.

The cranberry is in full bloom the first week of July and the harvest starts early in September. Fertilizer applications should be broadcasted directly after the June reflow if the treatment is to be fully effective the year of its application.

CRANBERRY SOILS

Cranberry soils are of three different types, Savannah, mud and iron-ore bottom. Geologically, all of are alluvial origin of comparatively recent formation. All are underlaid with a hard-pan very impervious to water. The Savannah is made up of a coarse sand together with enough organic matter to give it a black color. The native growth on Savannah consists chiefly of leather leaf or cassandra (*Chamaedaphore calyculata*). The mud is the peaty substance deposited in the bottom of cedar swamps, and may be from a few inches to 20 feet thick. Iron-ore bottom has the same general appearance as mud, but just below the surface a substance rich in iron, known locally as bog iron ore, is found. The Savannah is the only soil discussed in this paper.

METHODS USED

Absolutely controlled conditions such as are used in pot experiments with upland crops are impracticable with cranberry soils, because of the nature of the plant and its management. A uniform covering of cranberry plants is necessary to determine the ability of the soil to produce fruit, and such a covering would require 6 to 8 years. The regular flooding for insect pests and the careful irrigation are features hard to reproduce in the greenhouse. The relation of the long winter flooding to residual plant-food in the soil would be a difficult problem.

Field experiments where treatments were made on plants already in bearing and allowing for numerous untreated plots seemed to meet the more important needs of the situation. However, constant inspection of such an experiment is necessary in order to evaluate outside factors, such as insect injury and fungus disease.

In reporting results, the treated plot is compared with the average of the two untreated plots between which it is located. The following is given as an example:

PLOT	TREATMENT	YIELD	GAIN
		lbs.	*per cent*
51	Nothing	50	
52	300 pounds nitrate of soda	60	33⅓
53	Nothing	40	

$$60 - \frac{40+50}{2} = 60 - 45 = 15 \qquad \frac{15}{45} = 0.33\tfrac{1}{3}, \text{ or } 33\tfrac{1}{3} \text{ per cent}$$

The treatment and the yield are given invariably in pounds per acre.

MATERIAL	ANALYSIS OF SUBSTANCES USED
Nitrate of soda	15½ per cent nitrogen
Ammonium sulfate	20½ per cent nitrogen
Dried blood	10 per cent nitrogen
Cottonseed meal	5 per cent nitrogen
Acid phosphate	16½ per cent available "phosphoric acid"
Basic slag	19 per cent phosphoric acid
Rock phosphate	30 per cent total "phosphoric acid"
Steamed bone	1½ per cent ammonia; 60 per cent phosphoric acid
Bone meal	2 per cent ammonia; 30 per cent phosphoric acid
Muriate of potash	50 per cent "actual potash"
Sulfate of potash	48 per cent "actual potash"
Kainit	12 per cent "actual potash"
Calcium cyanamide	19 per cent nitrogen
Barium phosphate	25 per cent total "phosphoric acid"

EFFECT OF DIFFERENT KINDS OF PLANT FOOD

The first work in determining a cranberry fertilizer was to find the kinds of plant-food to which the cranberry plant responds. Plant-food from various common sources was applied to typical Savannah land and the results recorded. The first treatments were made in 1913. Nitrogen at the rate of 40 pounds to the acre, phosphoric acid 80 pounds, and potash 100 pounds, both alone and in combination with each other, were applied annually. After 3 years the vegetative growth became so great that it was concluded that the applications were too large, and further treatments were omitted until 1918. In this year half the original amounts of nitrogen and phosphoric acid were used, no potash was added in 1919, and 1920 no treatments were made.

The results set forth in table 1 represent increases over check plots for each year.

Insect enemies have a peculiar way of attacking a partly fertilized bog. Not only do they attack the well fed vines simply because of the more numerous tips, but also on account of the more trash on the floor of the bog. This latter condition especially meets the requirements of the blossom worm. In 1914, there was a general attack from this pest, causing a falling off in the yield of all the fertilizer plots, and in 1919 the attack was so concentrated on the treated plots that practically the entire crop was taken. For this reason, no crop record was made in 1919. Another insect, the cranberry girdler, finds a home on the treated plots and soon manages to reduce the crop and sometimes entirely kills the vines on the plots attacked. It was this insect that caused the loss on plots 25, 27 and 29. Of course, if these insects attack the check plots as well as the treated plots, there would be no need of making the special note of them, but their attack is almost entirely localized on the treated plots.

TABLE 1

Summary of effects of various fertilizer mixtures on the yield of cranberries

PLOT	TREATMENT PER ACRE	INCREASE OVER CHECK							
		1913	1914	1915	1916	1917	1918	1920	Average
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1	280 lbs. nitrate of soda	24	−8	109	−13	−8	−28	1	15
3	200 lbs. ammonium sulfate	5	−18	31	1	−45	−29	−21	−11
5	400 lbs. dried blood	−5	2	108	27	23	37	10	29
7	600 lbs. cottonseed meal	10	−6	84	18	40	33	−9	24
9	280 lbs. nitrate or soda 500 lbs. acid phosphate 200 lbs. muriate of potash	42	32	62	99	21	28	47	47
11	200 lbs. ammonium sulfate 500 lbs. acid phosphate 200 lbs. muriate of potash	4	7	34	71	−3	−15	53	22
13	400 lbs. dried blood 500 lbs. acid phosphate 200 lbs. muriate of potash	85	7	85	112	16	1	−4	43
15	600 lbs. cottonseed meal 500 lbs. acid phosphate 200 lbs. muriate of potash	41	41	122	88	2	−36	15	39
17	500 lbs. acid phosphate	1	10	56	82	15	−20	14	23
19	500 lbs. basic slag	14	16	46	14	16	5	12	18
21	300 lbs. rock phosphate	−5	36	96	59	38	16	32	39
23	300 lbs. steamed bone	35	50	48	95	17	20	8	39
25	600 lbs. bone meal 200 lbs. ammonium sulfate 200 lbs. muriate of potash	−17	25	38	109	−19	38	−38	19
27	500 lbs. basic slag 280 lbs. nitrate of soda 200 lbs. muriate of potash	13	111	48	103	−12	−54	23	33
29	300 lbs. rock phosphate 200 lbs. ammonium sulfate 200 lbs. muriate of potash	17	28	−1	23	−48	−42	−67	−15
31	300 lbs. steamed bone 200 lbs. ammonium sulfate 200 lbs. muriate of potash	1	3	60	50	9	−39	−5	11

TABLE 1—*Continued*

PLOT	TREATMENT PER ACRE	INCREASE OVER CHECK							
		1913	1914	1915	1916	1917	1918	1920	Average
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
33	200 lbs. muriate of potash	18	−22	5	−14	8	−2	39	5
35	200 lbs. sulfate of potash	27	34	51	19	−5	4	39	24
37	840 lbs. kainit	25	17	−3	8	−14	−22	−2	−1
39	200 lbs. sulfate of potash 200 lbs. ammonium sulfate 500 lbs. acid phosphate	38	1	67	30	5	96	54	42
41	840 lbs kainit 200 lbs. ammonium sulfate 500 lbs. acid phosphate	21	−1	17	11	6	−3	64	16

At the end of 1915 the vine growth was so great that some pruning was thought advisable and the excessive growth cut from some of the plots. The following list shows which plots were pruned and the weight of the vines removed.

PLOT	POUNDS	PLOT	POUNDS
1	55.50	25	68.00
5	68.30	27	97.50
7	53.75	29	88.00
9	102.00	31	86.00
11	77.00	39	60.50
13	33.75	41	45.00
15	34.00		

Discussion of results

Nitrate of soda started with a good increase the first year, but suffered a loss through insects the second year. The third year it gave an excellent increase, although it had poor staying qualities. The increase dropped to 13 per cent as soon as applications ceased, and then dropped to a loss in 1917 and 1918. It is safe to say that nitrate of soda has a quick action and stimulates vine growth enormously.

Ammonium sulfate, because of its acid reaction, was thought to be ideal for cranberry land at the beginning of the experiments. It was used wherever there was a choice in the complete fertilizers. However, where it was used alone it seemed to injure the vines directly, causing a sickly yellow appearance. This plot did not have vine growth enough to warrant pruning in 1916, nor was the crop especially large. Even after the limestone treatment of 1918,

the plot did not recover. From the action on this plot the writer feels that ammonium sulfate is an unsatisfactory source of nitrogen for cranberry land.

Dried blood started slowly but its action seemed well suited to the cranberry and its average is the best received from any of the sources of nitrogen.

Cottonseed meal acted in a manner somewhat the same as dried blood but on the whole the results were not as satisfactory as those obtained from dried blood.

The results with nitrogen from organic sources check well with those obtained on upland crops, namely that such sources do not return nitrogen pound for pound as effectively as do mineral sources of nitrogen. When we consider that the application of 380 pounds of nitrate of soda is undoubtedly an overdose, we feel that 400 pounds of dried blood must furnish nearly the required amount of nitrogen. In other words, 40 pounds of nitrogen applied in the form of dried blood would give a result nearly equal to the result of a treatment of 20 pounds of nitrogen in the form of nitrate of soda on upland crops, and the same seems to be true on cranberry soil.

Acid-phosphate gave moderate increases from the first, and the average was satisfactory. Its valuable characteristic is its early availability.

Basic slag returned a steady but moderate increase in yield. It was also quick to start.

Rock phosphate was slow to start but gave an excellent crop after the first year. It is probably one of the best sources of phosphoric acid on cranberry soil.

Steamed bone has a small nitrogen content and we must take this into consideration when we compare its effect with that of the phosphatic non-nitrogen treatments. Its increases are rather quick and even, although the average is just equal to the rock phosphate increases.

With the potash the results are rather "hit or miss," but sulfate of potash shows itself to be an even yielder of gains and is probably the best source of potash.

The increases resulting from the complete fertilizer do not lead to any further discussion except that all showed effects of an over fertilization, and that plots 25, 27 and 29 suffered a heavy attack by the cranberry girdler.

In brief, the best sources of nitrogen are nitrate of soda and dried blood; of phosphoric acid, phosphate rock; and of potash, sulfate of potash.

II. AMOUNT AND SOURCES OF NITROGEN

The second problem undertaken was the determination of the optimum amount of nitrogen to be applied to cranberry soil and to compare the effect of nitrogen drawn from the mineral and with that from organic sources. The first study showed that 40 pounds of nitrogen was too much to apply annually, and according to the experience of one of the larger growers 10 pounds was too little. Obviously the optimum was somewhere between these amounts and it was decided to try 20 and 30 pounds.

The treatments and results are recorded in table 2.

Discussion of results

The addition of 140 pounds of sodium nitrate to the acre the first year caused an increase of 37 per cent and the second year of 80 per cent. The treatment of 210 pounds of sodium nitrate first caused an increase of 91 per cent, but the second year it dropped to 58 per cent. This indicates that 30 pounds of nitrogen drawn from sodium nitrate is too great for annual applications, while 20 pounds seems to be nearer the correct amount.

With dried blood the reverse is true, namely, that 30 pounds of nitrogen drawn from the dried blood gives a better yield than 20 pounds. This bears out the conclusion drawn under the first experiment.

TABLE 2

Results of nitrogen experiments on Savannah soil, variety Early Black

PLOT	TREATMENT PER ACRE	NITROGEN APPLIED	1919		1920	
			Yield per acre	Increase over checks	Yield per acre	Increase over checks
		lbs.	*lbs.*	*per cent*	*lbs.*	*per cent*
F-SB-N 1	Nothing		3320		3680	
F-SB-N 2	140 lbs. sodium nitrate	20	4280	37	6020	80
F-SB-N 3	Nothing		2920		3020	
F-SB-N 4	70 lbs. sodium nitrate; 85 lbs. dried blood	20	4400	48	4920	54
F-SB-N 5	Nothing		3000		3400	
F-SB-N 6	170 lbs. dried blood	20	3200	−2	4320	12
F-SB-N 7	Nothing		3560		4300	
F-SB-N 8	210 lbs. sodium nitrate	30	7320	91	6000	58
F-SB-N 9	Nothing		4100		3300	
F-SB-N 10	105 lbs. sodium nitrate; 127½ lbs. dried blood	30	4660	21	4850	84
F-SB-N 11	Nothing		3160		1980	
F-SB-N 12	255 lbs. dried blood	30	3920	10	2680	52
F-SB-N 13	Nothing		3900		1540	

The increase due to the mixture affording 20 pounds of nitrogen was half way between the increases from the ingredients themselves in 1920, but with a treatment yielding 30 pounds of nitrogen, the increase was more than from either of the ingredients used alone. The reason for this is that the plot receiving nitrate of soda alone has an overdose, while the other plots are receiving less than they can profitably use.

III. CALCIUM CYANAMIDE AS A SOURCE OF NITROGEN

Calcium cyanamide is a relatively new source of nitrogen on the American market and its advantages are little known. In 1919 tests were started to determine its use as a source of nitrogen. The yield was so disappointing at the end of the first year that no new treatment was made in 1920, but the residual effect was recorded. The results are given in table 3.

It seems that the result the first year did not show the full advantage of the application of calcium cyanamide. The distinct loss where calcium cyanamide alone is used the first year is more than made up the second year. The addition of ground limestone does not materially help the treatment.

TABLE 3

Results of tests with calcium cyanamide on Savannah soil, variety Late Howe

PLOT	TREATMENT PER ACRE, 1919 ONLY	1919		1920	
		Yield per acre	Increase over checks	Yield per acre	Increase over checks
		lbs.	*per cent*	*lbs.*	*per cent*
1	Nothing	5680		5653	
2	120 lbs. calcium cyanamide	4900	−17	5653	28
3	Nothing	5900		3147	
4	120 lbs. calcium cyanamide 250 lbs. acid phosphate 220 lbs. sulfate of potash	6000	2	4720	44
5	Nothing	5900		3413	
6	120 lbs. calcium cyanamide 2000 lbs. ground limestone	4740	−20	5113	20
7	Nothing	5900		5113	
8	120 lbs. calcium cyanamide 250 lbs. acid phosphate 220 lbs. sulfate of potash 2000 lbs. ground limestone	6340	6	5387	5
9	Nothing	6040		5113	

IV. THE DETERMINATION OF THE OPTIMUM AMOUNT OF PHOSPHORIC ACID FOR CRANBERRY SOIL

It was recognized that a sufficient amount of phosphoric acid is lacking in most cranberry soils, but the amount that may be applied economically each year is not definitely known. The study here reported is designed to throw light on this problem.

In former investigations reported in this paper phosphoric acid derived from acid phosphate gave immediate returns; on the other hand, phosphoric acid derived from rock phosphate gave no increase until after the first year, but when it began to operate in any marked degree, its results were far better than those of acid phosphate. Rock phosphate, because of its alkaline reaction, did not leave an undesirable residue in the soil and it was the most beneficial of the materials tested. This was used as a basis of the treatments.

As rock phosphate would not become effective before the second year, a treatment was made of an equal amount of phosphoric acid drawn from acid phosphate. This extra treatment was to furnish phosphoric acid for the first year, thc treatment in following years, except on plot 14, to be merely rock phosphate. The treatments and yields are given in table 4.

TABLE 4

Results of phosphate tests, variety Early Black

PLOT	TREATMENT PER ACRE	P_2O_5	1919		1920	
			Yield per acre	Increase over checks	Yield per acre	Increase over checks
		lbs.	*lbs.*	*per cent*	*lbs.*	*per cent*
1	Nothing		2440		2310	
2	125 lbs. acid phosphate (1919 only)	20				
	75 lbs. phosphate rock	20	2280	−3	2210	12
3	Nothing		2240		1470	
4	250 lbs. acid phosphate (1919 only)	40				
	150 lbs. phosphate rock	40	3720	29	2240	1
5	Nothing		3520		2960	
6	375 lbs. acid phosphate (1919 only)	60				
	225 lbs. phosphate rock	60	3200	−4	3960	40
7	Nothing		3120		2500	
8	500 lbs. acid phosphate (1919 only)	80				
	300 lbs. phosphate rock	80	3580	17	4540	79
9	Nothing		3000		2480	
10	150 lbs. phosphate rock	40	3000	2	2320	6
11	Nothing		2880		2460	
12	150 lbs. soft phosphate rock	40	2840	−2	2220	−2
13	Nothing		2920		2060	
14	250 lbs. acid phosphate	40	3440	11	2160	19
15	Nothing		3360		1560	

Discussion of results

The clear-cut nature of the results is somewhat obscured by the erratic yields on the check plots. However, it is clear that the highest yields and the greatest percentum increase are obtained on the plots receiving the greatest amount of phosphoric acid. The remarkable increase of 79 per cent after treatments of 300 pounds of phosphate rock shows the poverty of the soil with respect to phosphoric acid.

Soft phosphate rock did not show any advantage over the Tennessee phosphate rock.

The experiments are to be carried on through several years in order to obtain a definite knowledge regarding the total quantity of phosphate rock that may be economically added to cranberry soil.

V. BARIUM PHOSPHATE AS A SOURCE OF PHOSPHORIC ACID

Barium phosphate is a new source of phosphoric acid of which we know comparatively little, except that it is a by-product of the iron ore industry. It has been highly recommended at some of the experiment stations, but its use has met with failure at others. It was considered worth a trial on cranberry land, at any rate.

The yields were unsatisfactory after the first treatment and no new treatment was made in 1920. The residual effect on the crop has been recorded. The results are given in table 5.

TABLE 5

Results of tests with barium phosphate, variety Early Black

PLOT	TREATMENT PER ACRE	P_2O_5	1919 Yield per acre	1919 Increase over checks	1920 Yield per acre	1920 Increase over checks
		lbs.	*lbs.*	*per cent*	*lbs.*	*per cent*
1	Nothing		2920		2060	
2	250 lbs. acid phosphate	40	3440	11	2160	19
3	Nothing		3360		1560	
4	150 lbs. phosphate rock and 7 per cent barium sulfide (1919 only)	40	3560	8	2240	47
5	Nothing		3160		1540	
6	150 lbs. soft phosphate rock and 7 per cent barium sulfide (1919 only)	40	3240	9	2600	49
7	Nothing		2760		1940	
8	150 lbs. barium sulfide (1919 only)	40	2400	−9	1980	8
9	Nothing		2480		1720	

The use of barium phosphate cannot be recommended from the results of the reported test.

VI. THE OPTIMUM AMOUNT OF A TENTATIVE MIXED FERTILIZER TO BE APPLIED TO SAVANNAH SOIL

The experiment station investigators felt in 1919 that they were ready to publish a tentative formula for a complete fertilizer for Savannah land, and undertook tests to determine as nearly as possible the amount needed for annual applications. The mixture was made up on the basis of the results obtained since 1913, and consists of the following:

	lbs.
Sodium nitrate	75
Dried blood	75
Rock phosphate	300
Sulfate of potash	50

The first year this material was used 300 pounds of acid phosphate was added in order to have phosphate available the year of application. The results of two years' tests are given in table 6.

Plot 8 received what was obviously an overdose of fertilizer in 1919, and the experimenter did not feel justified in repeating the application in 1920. Consequently, the yield from this plot in 1920 was influenced only by the residual effect.

TABLE 6

Results of tests with different amounts of the cranberry fertilizer mixture

PLOT	TREATMENT PER ACRE	1919		1920	
		Yield per acre	Increase over checks	Yield per acre	Increase over checks
		lbs.	*per cent*	*lbs.*	*per cent*
SB-F-C-1	Nothing	3800		1540	
SB-F-C-2	264 lbs. mixture 176 lbs. acid phosphate*	4780	20	2520	61
SB-F-C-3	Nothing	4000		1580	
SB-F-C-4	528 lbs. mixture 352 lbs. acid phosphate	5180	20	2620	68
SB-F-C-5	Nothing	4680		1540	
SB-F-C-6	792 lbs. mixture 528 lbs. acid phosphate	6340	38	3680	82
SB-F-C-7	Nothing	4500		2500	
SB-F-C-8	1056 lbs. mixture 704 lbs. acid phosphate	5200	49	2980†	45
SB-F-C-9	Nothing	2860		1600	

* The acid phosphate was added in 1919 only.

† No fertilizer applied in 1920.

The percentage increases over the checks for both years show that plot 5, receiving 792 pounds of the mixture, gave the best results. From observation in the fall of 1920 this plot was in the best condition to produce a crop in 1921. The yield from the plot receiving 528 pounds of the mixture was very close to that from the one receiving the larger amounts, but the action was somewhat slower. For a bog in a run-down condition like this one, an application of 792 pounds of the mixture will certainly pay good dividends to the grower.

VII. EFFECT OF FERTILIZER APPLICATIONS OTHER THAN ON THE YIELD

Plant-food applications create other differences than in the total yield. Probably the most important difference is in the size of the individual fruits which varies directly with the available plant-food. A single example of this tendency has been selected from the plant-food studies and is fairly typical. The three plots chosen were in a bog badly in need of plant-food; one received nothing, the second received a single application of a complete mixture and the third received a double application of the same mixture. Applications were made in 1917, and the size of the berries was measured in 1918 and 1919. The number of berries required to fill an inspector's cup has been taken as the measurement, and the published data represent the average of three

TABLE 7

Results showing effect of fertilizer on size of cranberries

PLOT	TREATMENT PER ACRE (SUMMER OF 1917 ONLY)	SIZE OF BERRIES (NUMBER PER MEASURE)	
		1918	1919
1	Nothing	169	123
2	1000 lbs. mixture	128	110
3	2000 lbs. mixture	112	93

TABLE 8

Results showing effects of fertilizer on quality of cranberries

PLOT	TREATMENT PER ACRE	BERRIES AFFECTED BY ROT	
		1918	1919
		per cent	*per cent*
1	Nothing	19	84
2	1000 lbs. mixture	11	2
3	2000 lbs. mixture	21	58

counts made of a lot of berries. The larger numbers of berries indicate the smaller size of the individuals.

A second difference is in the health of the individual fruits. Table 8 shows the proportion of berries affected by rot in the plots mentioned above.

There is an enormous difference in the amount of rot between the two years recorded, but aside from this, there is a definite difference in the percentage of rot between the individual plots. Plot 2, receiving about the correct amount of plant-food, had the fewest rotten berries both years, while the other plots had a very high proportion of rot.

A third effect of fertilization is in vine growth. This is especially noticeable on the plots receiving nitrogen, where the plants start their growth earlier in spring and stay green later in the fall. The individual leaves are larger and greener than those in the untreated plots.

Indirectly due to the quickened vegetative growth, the treated plots show a smaller number of weeds, a large number of which are crowded out by the well-fed cranberry vines. This is especially true of red root (*Lachnanthis tinctoria* Ell.). Annual weeds are prevented from starting because of lack of space for seed germinating.

DISADVANTAGES OF FERTILIZATION

The more vigorous vine growth caused by fertilizer treatments is very attractive to many insect pests, more particularly the blossom worm and the cranberry girdler. Extensive areas well fertilized have borne large crops four or five years and suddenly stopped through no apparent reason, but the following season dead vines appear here and there and the next year dead spots sometimes a half-acre in extent are common. This is the work of the cranberry girdler.

The most serious injury caused by the blossom worm is its cutting off of the stem of the blossom. It can easily hide in thick vines and so does most of its work there. Both of these pests are easily controlled by submerging the cranberry bog and a careful grower will provide sufficient water supply before he uses fertilizer extensively. Good practice demands that careful inspection be made for these pests, so that the water may be used before they have ruined a crop or a bog.

SUMMARY

The cranberry bog because of its peculiar soil and water conditions requires a special fertilizer mixture.

The most profitable sources of nitrogen appear to be nitrate of soda and dried blood. Sulfate of ammonia is an unsatisfactory source of nitrogen. Acid phosphate and rock phosphate were efficient sources of phosphoric acid. Sulfate of potash and muriate of potash were good sources of potash.

In the production of cranberries 20 pounds of nitrogen drawn from nitrate of soda appears to be as efficient as 30 pounds of nitrogen drawn from dried blood. Twenty pounds of nitrogen from nitrate of soda gave excellent returns on Savannah cranberry land.

Calcium cyanamide as a source of nitrogen is of doubtful value.

Cranberry bogs seem to be very deficient in phosphoric acid, applications as high as 80 pounds of actual phosphoric acid per acre producing large increases in crop.

Cranberry bogs respond readily to applications of the complete fertilizer mixture, from 500 to 800 pounds per acre giving the best results.

Over-fertilization causes excessive vine growth and soft berries, and such a practice makes the vines very susceptible to insect attack.

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